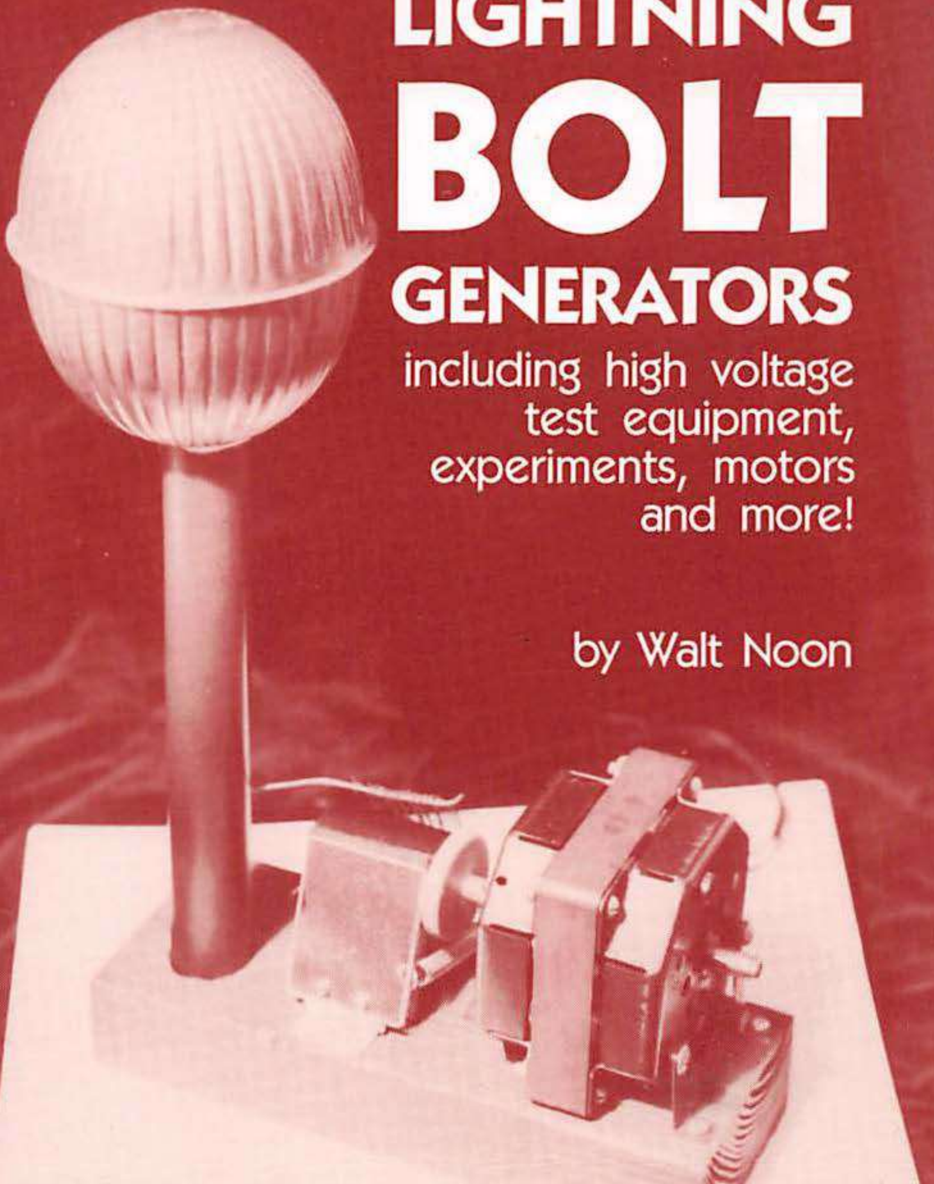
Secrets of Building Electrostatic

LIGHTNING BOLT GENERATORS

including high voltage test equipment, experiments, motors and more!

by Walt Noon



Lindsay Publications Inc

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To my Mom and Dad who always took the time to answer my questions

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Special thanks to
Kevin E. Curtin
Matthew J. Roddy
Mike Noon

WARNING

The author of this book is not a professional engineer nor has he had formal training in the design or operation of high voltage devices. The author is an amateur but has been successful in building and operating the devices discussed herein.

The methods that he used and describes are presented merely as guidelines for other amateurs in developing similar devices. These devices can be dangerous, possibly even lethal, and dangers have been pointed out wherever possible. Since the author is not a professional in this field, there may well be other dangers involved in the building and operation of the devices described.

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Every text I've seen on the subject of electrostatics seems to begin with a history of the subject. A. D. Moore, one writer whose works I particularly enjoy, said that if cavemen had cats that rubbed up against them then they must certainly have been aware of the presence of static electricity. There are theories now going around the scientific community that claim lightning triggered the formation of the first chains of DNA. I'll take that one step further and guess that lightning began the evolutionary process that created our species.

Static electricity is one of the most fascinating and possibly most overlooked fields of modern electronics. We all take static for granted. Before I began experimenting with static electricity it would have been very difficult to convince me that it was easy to get 3500 volts from an old plastic bottle or 10,000 volts and more from a rubber band! Even now as I watch one of these tiny generators in action it is difficult to imagine that it is producing these voltages.

As you learn about electrostatics you will find many strange and wonderful experiments to perform. For example, it is possible to mysteriously levitate objects, blow a candle flame to one side with an invisible wind, and to light neon bulbs without wires.

There are motors that can be built to run on static electricity! Well-made electrostatic motors are so sensitive that they have been powered by the earth's natural electrical charge alone! Connect your motor to an antenna, and off it goes!

In addition to the many curiosities static electricity makes possible, there is also the potential for serious research with many astounding possibilities.

Consider the work of Professor John G. Trump, formerly of the Massachusetts Institute of Technology. Professor Trump points out that electrostatic forces are the most powerful forces known in nature – stronger by far than gravity or magnetism. Professor Trump demonstrates the practical application of electrostatic generators with the following illustration:

Consider two conductive plates, 100 square inches in area, facing each other and separated by an insulator. If the plates are each charged oppositely to 300 volts per centimeter the force of attraction between them will be one 2,000th of a pound. Increase this charge to 30,000 volts per centimeter and the attraction escalates to half a pound. Now increase this voltage to the order of three million volts per centimeter and the force of attraction jumps to 5,700 pounds! As Trump has said "Force of this order has more than a passing interest for power engineers." Trump and his colleagues had been pursuing the creation of electrostatic generators they hoped would one day rival modern electromagnetic generators.

Just how much electrostatic energy is theoretically possible? Consider an aluminum cube only one centimeter square. Imagine that all the electrons in that cube were removed and kept one meter away. The cube has only positive charges, and the electrons one meter away only negative charges. Since positive and negative charges attract, what would be the force of attraction generated between them? The answer turns out to be an astounding thirty-two million million million million pounds! Professor A.D. Moore, an expert in electrostatics, points out that this force would be equal to the weight of a steel cube 76 miles high!

Of course, as much fun and as inspiring as it is to ponder the theoretical world of electrostatics, back in the real world we find that electrons don't leave home so easily. The most useful electrostatic inventions to date make use of the 'little' forces of electrostatics. But keep that cube in mind and let everyone wonder why you have that curious smirk on your face whenever you run your generator.

What voltages are possible for the experimenter? The four easily assembled generators shown in the following text will give you an idea. Each one intentionally operates on a slightly different principal of gathering an electrostatic charge. If you build them, or just simply become familiar with them, you will develop a understanding of the most popular ways of generating static electricity.

I am confident that if you become acquainted with these machines you will have no difficulty at all in constructing many others of your own design. The reason that I am so confident is that I designed and constructed all of these machines to teach myself about electrostatics! Each machine represents the best of my thoughts at the time I con-

structed it.

You will soon find that it is easily possible to construct a static generator capable of producing 50 to 100 thousand volts! If you are a craftsman, 200 thousand volts and more can be obtained by optimizing the designs of the higher power generators such as the Van De Graaff shown later in the text.

Electrostatic generators are also remarkably inexpensive. With a little foraging through the surplus bins, no generator in this text cost me more than $30 to build! I know of no other way to approach these voltages for such a low cost.

A Little History of the First Practical Generators

The first electrostatic generators produced their voltage with friction. Towards the end of the 17th century Otto von Guericke, an amateur physicist from Magdeburg, developed the first practical electrical machine – an electrostatic generator. What follows are his own instructions for building one:

"Secure one of the glass globes which are called phials, about the size of a youngster's head; fill it with sulfur, ground in a mortar and melted by the application of flame. After it freezes, break the phial, take out the sulfur globe and keep it in a dry place, not a moist one. Perforate it with a hole so that it can spin upon an iron axle. Thus the globe is prepared.

"To demonstrate the power developed by this globe, place it with its axis on two supports in the machine – a hand's breadth above the baseboard – and spread under it various sorts of fragments such as bits of leaves, gold dust, silver filings, snips of paper, hairs, shavings, etc. Apply a dry hand to the globe so that it is stroked or grazed two or three times or more. Now it attracts the fragments and, as it turns on its axis, carries them around with it.

"When a feather is in contact with the globe, and afterwards in the air, it puffs itself out and displays a sort of vivacity ... and if someone places a lighted candle on the table and brings the feather to within a hand's breadth of the flame, the feather regularly darts back suddenly to the globe and, as it were, seeks sanctuary there."

Otto Von Guericke goes on to describe experiments by which he produced both light and sound from his amazing globe!

The instructions for von Guericke's globe are simple enough for any experimenter today to follow. The only note that I would add is

that in casting my own globe I found that large quantities of sulfur would become much smaller pools when melted, and that if the globe were not filled on the first pouring it would not appear nearly as attractive when finished. So, remember to begin with a large amount of sulfur.

THE ELECTROPHORUS

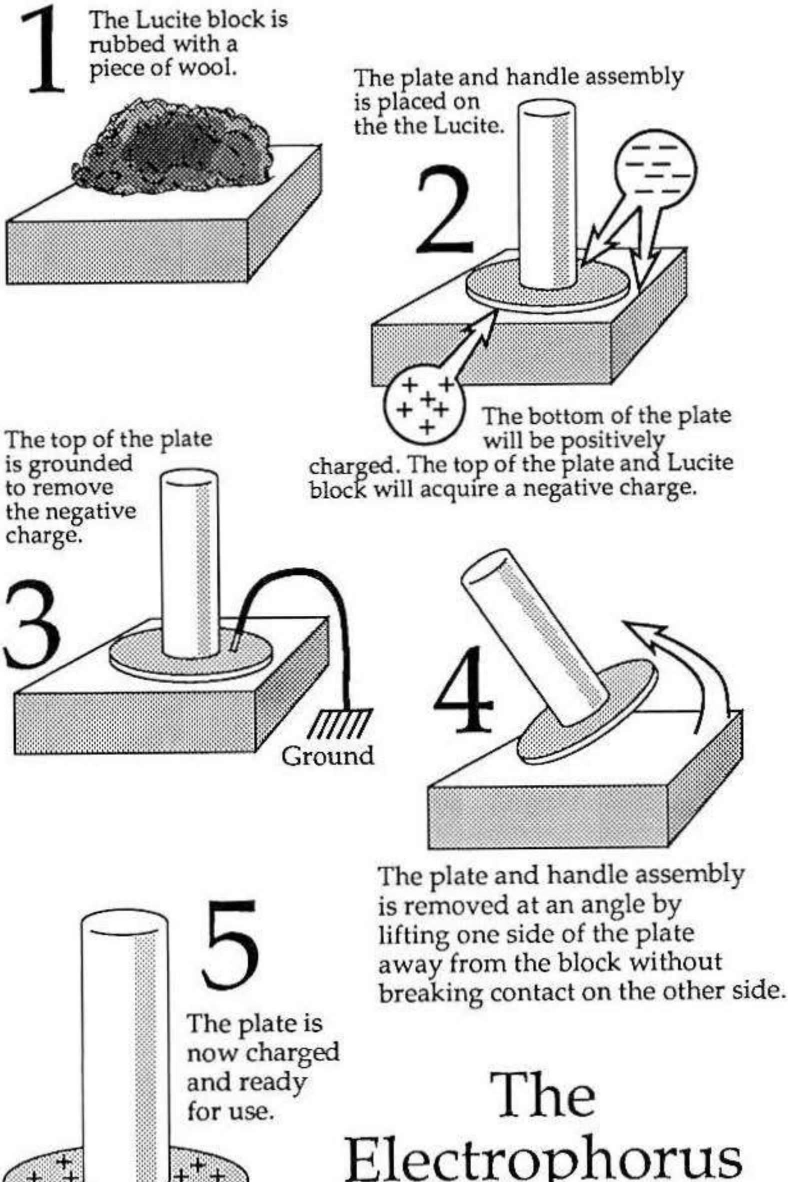
Many generations passed and many ingenious machines were developed without great change using materials and processes similar to von Guericke's globe. The most important historically was Alessandro Volta's *electro perpetuo* known now as the electrophorus. With it we can dramatically demonstrate that electrostatic charges are much like magnetic forces in that like charges repel one another while opposite charges attract.

An electrophorus is very easily assembled. It consists simply of a rectangular block of insulating material such Lucite or, better yet, polyethylene and a metal disk which is attached to an insulating handle (Figure 1).

When the Lucite is rubbed with a woolen cloth, electrons are removed from the cloth and held on the Lucite. This happens because the cloth will hold its electrons less tightly than the Lucite. An insulating material, in this case Lucite, by its nature, will not allow the electrons to move around freely. The charges are therefore 'static' or held in place by the insulating material. The Lucite will now have a negative charge, and the wool will pick up a positive charge, respectively.

Next, the metal disk with the handle is set on top of the Lucite. The negative charges on the Lucite are attracted to positive charges on the metal disk, so, the positive charges in the metal disk move to the side of the metal plate facing the Lucite. The negative charges are similarly repelled to the back of the metal disk. Now, your hand or, better yet, a ground wire are touched briefly to the top (handle side) of the metal disk and then removed. In this way the negative charge is transferred to your hand (or ground) leaving only a positive charge. The metal plate will now have a positive charge, and the plastic negative.

If you have achieved a large enough charge, the Lucite can be picked up by the metal disk!



The Electrophorus

Figure 1

Slowly remove the metal plate by the handle, drawing it away from the Lucite at an angle. The metal plate now holds the charge you seek. Having charged your electrophorus, you can perform the experiments with Von Guericke's globe mentioned above including attracting hair, styrofoam and other small objects.

Because the charged surface of the electrophorus is flat, a startling demonstration can be performed wherein the electrophorus disk is actually floated above the Lucite by electrostatic forces. Performing this trick takes some practice. Make a second metal plate and handle. Remember that if the plate is to float above the other it must be very light weight. (Figure 2)

Now, we have the challenge of charging both the disk and the Lucite with a like charge so that they will repel each other. Charge your first disk with a positive charge as described above, and then bring it close to, but not touching, the second disk. This will charge the second disk by attracting a negative charge to the front of the disk. Next, ground the handle side of the second disk to bleed off the positive charge. The second disk is now negatively charged. The Lucite is also negatively charged, so, provided everything has been accomplished and the weight is not too great, the second disk will now float above the Lucite block!

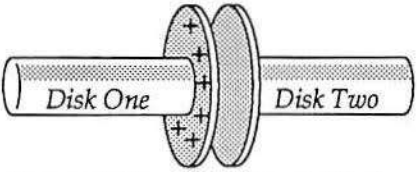
Electrophoruses act a great deal like capacitors discussed later on and can be used for many surprising experiments including charging a Leyden jar and flickering a neon bulb in a darkened room!

Special Notes on Friction Generators

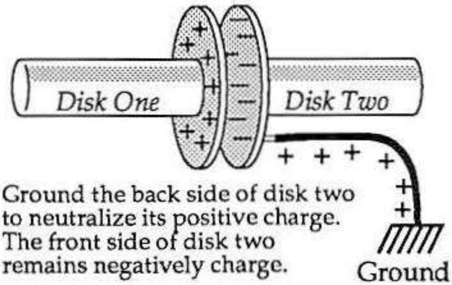
Before we move on to the more powerful friction generators, there are a number of things you should be aware of that will help you in both troubleshooting and designing generators.

My first bit of advice is to avoid humidity. It makes air more conductive. Moisture in the air can have a devastating effect on the charges stored by electrostatic devices.

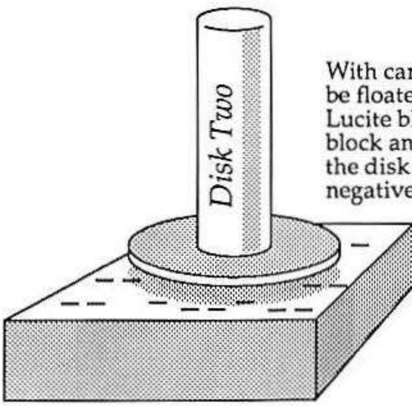
I was given a first rate example of this shortly after building my first two generators. Both machines, only days old in their construction, were whirling away in my shop. I was doing "careful scientific study" – in other words, I was zapping everything in sight to see what would happen. Suddenly, and most mysteriously, both generators



Charge disk one on the Lucite block.
Then bring it close to a second disk.



Ground the back side of disk two to neutralize its positive charge. The front side of disk two remains negatively charge.



With care disk two can be floated above the Lucite block. Both the block and bottom of the disk carry repelling negative charges.

Floating the Electrophorus

Figure 2

stopped producing a charge. I couldn't imagine why both, each being very different in construction, might fail at exactly the same time. Then the culprit made itself known! Just outside the door the automatic lawn sprinklers had come on and extremely humid air was coming through my door!

Another good example of this problem is demonstrated by walking across a padded carpet. When the relative humidity is 20% or less, charges of up to 35,000 volts can be obtained by shuffling one's feet along the carpet. However, raise the humidity to 60% or more, and the maximum charge will plummet to a mere 1,500 volts! If you live in a humid region, you may not be able to get the same performance from a generator that someone living in the desert might. Hopefully, humidity will only be a seasonal problem for you. Dry winter days are best.

There are fascinating static generators which are more or less immune to humidity. These rely on generating a charge by induction rather than by friction. These machines will also be discussed in detail later on.

Be careful in selecting paint for your generator. I have found that many spray paints contain ingredients that will conduct static electricity. For the most part I have had few problems with this, although in a darkened room I have seen the telltale blue corona glow of escaping electrons coming from painted plastic surfaces on a generator. To correct the problem I simply coated the nearby metal surfaces that were losing their charges to the paint with high resistance "corona dope" sold in T.V. and better electronic stores.

Avoid using wood to build generators. Although we think of wood as an insulator, in reality it becomes an excellent conductor of very high voltages. In the machines that follow, you'll see polyvinyl chloride (pvc) pipe used extensively. If you can get acrylic or phenolic tubing, use it. It offers much better dielectric strength.

Dust can bleed away a charge. Dust on a high potential terminal can reduce your generator's efficiency by a whopping 40%. Because your high potential terminal carries a charge, dust will be attracted to it in much the same way that dust accumulates on the front of a T.V. screen. I have actually seen a tiny particle of dust prevent an eighth inch spark from arcing. Keeping your terminal clean is important.

On the other hand, the attraction of dust to your generator can be

quite entertaining. One way that I enjoy cleaning my generator is to ground myself and then pass my hand over the high potential terminal. The dust which has been sitting there has acquired a high voltage charge and jumps to your hand which it sees as ground. The effectiveness of this method for really getting your generator clean is doubtful since after a few seconds the dust in your hand looses its charge and heads back for the generator, but it's lots of fun.

Once during a rare Southern California thunderstorm I observed a particularly confused particle of dust. Apparently the storm had charged the air, and my generator had charged a large particle of fluff. The fluff couldn't decide where it wanted to be and would repeatedly fly around my bench only to return to the generator and then again off into the air. It was an astounding sight.

SUPER FRICTION GENERATOR – ROTOSTATIC

Now that you understand the basics of how a charge is picked up by friction, doesn't it seem that it would be possible to design a mechanical means to make and store a charge automatically and continuously? One solution to the problem is what I call a "rotostatic" generator, so named for an old magazine article that called a similar device a "rotostat." I said earlier that it was possible to get 3500 volts from an old plastic bottle, and I wasn't kidding. All you have to do is build the "rotostat".

These generators are extremely simple to build and may be hand cranked or operated by a small electric motor. They consist simply of a plastic drum – an old plastic jar works great – and a rubbing block – wool, nylon, asbestos, leather. When the bottle is rotated against the rubbing block a charge is developed on the plastic and on the block.

We need to attach some metallic brushes to the side of the plastic drum opposite the block to pick up the charges as they are generated. The brushes are attached to a metal sphere where the charges can be stored. A complete schematic of a rotostatic generator is shown in figure 3.

There is an infinite variety of possible configurations for such a generator, but keep in mind in designing yours that for static voltages even wood is a good conductor. It is most important to remember to keep your high potential components well insulated from ground.

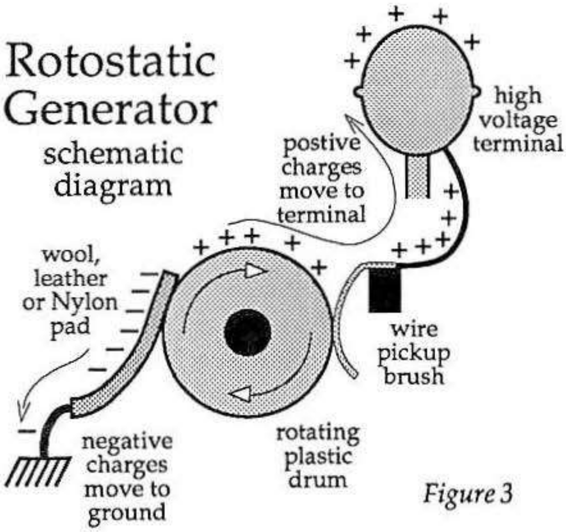


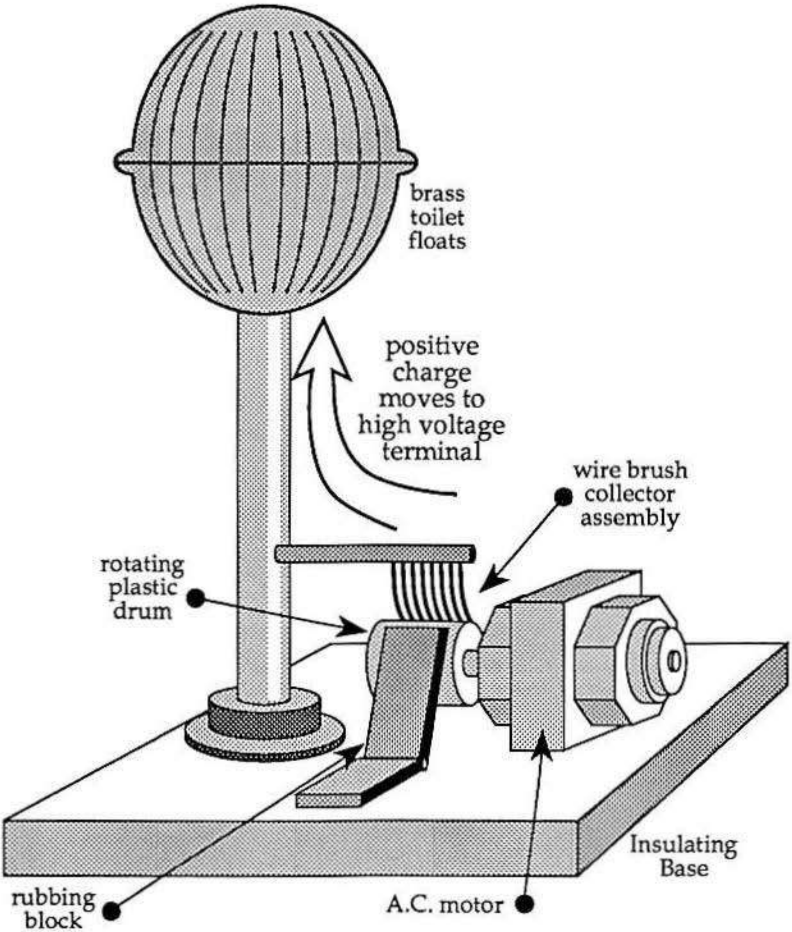
Figure 3

If your generator is well made it will generate enough power to light a neon bulb (Ne2 type), levitate styrofoam, and arc a spark perhaps as long as 1/16 to 1/8 inch – all of this while still being perfectly safe to touch. When touched, your generator will give your finger only a very light "pop" much like a very small static discharge from a doorknob. As an interesting side note, if you can feel a static charge at all, it will be at least 3,500 volts!

Though static machines deliver these high voltages, their rapid, low current discharges make them unusually safe. Even generators producing 100,000 volts or more rarely present a danger, though I for one would not intentionally take a shock from one. A later chapter on capacitors (energy storage devices) will give you an equation for finding out when a charge has become dangerous.

Building a Film Case Rotostatic Generator

In my rotostatic generator design I have attempted to maximize the output and storage capacity of this type of machine. I am sure that there are still many improvements that can be made. This device works extremely well, is reliable, and very easy to construct. A schematic and a photograph are shown in figure 4.



Rotostatic Generator

Figure 4

I used a surplus AC tape recorder motor to drive the unit. I like to use tape recorder motors in many projects because they are quiet and often have threaded axles that are very easy to mount components onto. In this case, I wanted to be able to switch plastic drums easily so I could experiment with a wide variety of materials. If you are unable to find such a motor, something similar can be used. A breakdown of

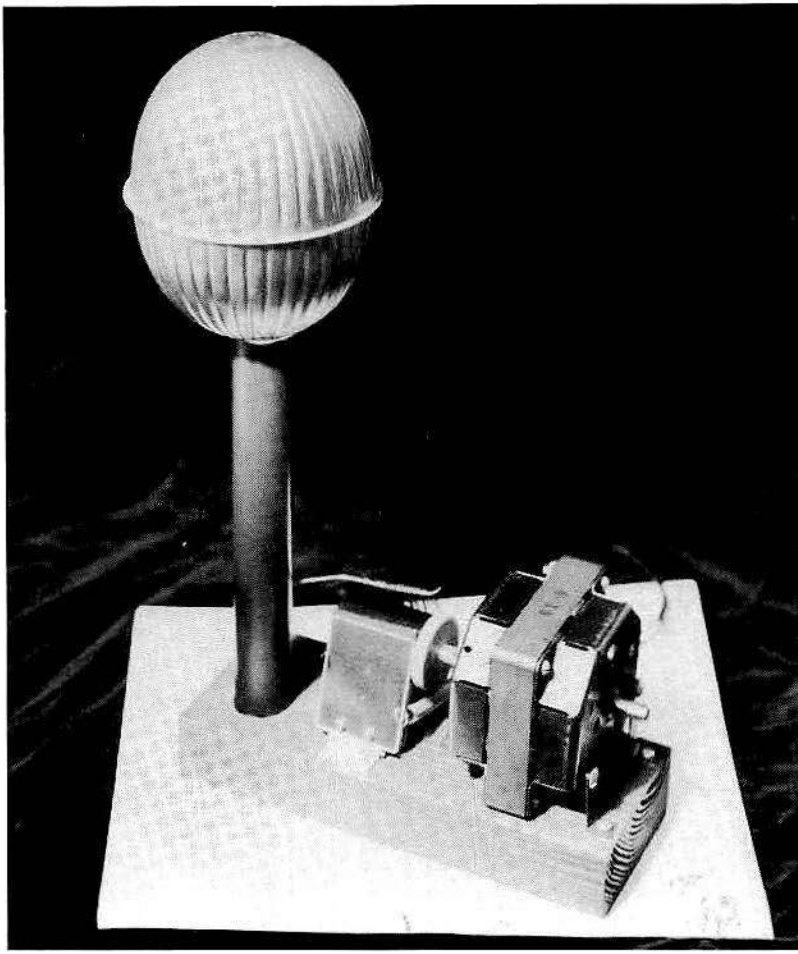


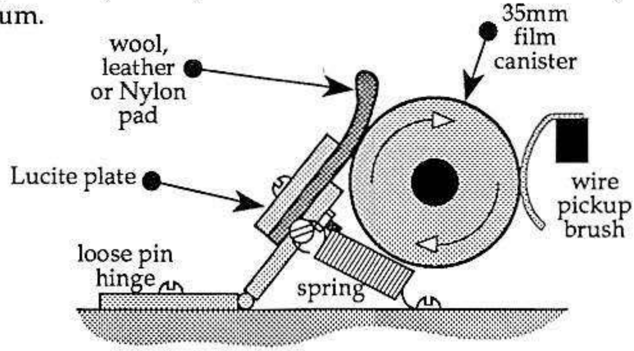
Fig. 5 – The complete Rotostatic Generator uses only a small plastic drum and a few common parts, and yet will light a hand-held 90 volt neon lamp!

AC and DC motors and their suggested hookups are shown in detail in the next chapter.

Assembly is straightforward and simple. The motor is mounted securely with wood screws to the base – in this case a section of 2x4. Make sure this connection is secure since in experimenting with different drums you will undoubtedly have some which will wobble due to imbalances in the drum or in the mounting. Also, remember to

select a motor with plenty of power. Tiny D.C. toy motors can work, but they have little torque and can stall, and that can be frustrating.

The drum can be mounted to the motor in a variety of ways. If the motor axle is hollow as the tape recorder axles are, you can simply use a screw to secure the bottle cap directly to the motor axle. If the axle is solid, you will probably want to extend the axle all the way through the drum.



Wiper Assembly
for Roto Static Generator

Figure 6

To mate the motor axle to the axle running through your drum, glue progressively larger pieces of plastic tubing to the smaller axle until the tubing size matches that of the larger axle, then slip the tubing over both axles. Tubing used as fuel line on model airplanes, aquarium tubing, compressor hose, and the insulation stripped from wire can be used to make excellent adapters. Heat shrink tubing can also be used, however, after it has been shrunk it tends to become somewhat brittle.

As long as the pieces of tubing fit tightly over one another, any glue can be used to hold them together. I like cyanoacrylate (Super Glue) because it seems to hold rubber tubing nearly as well as it does skin. If you have used "Super Glue" for any length of time will know what I mean by this.

This method of connecting a motor to an axle also has the beneficial effect of acting as a "universal" joint. That is, your motor can actually power your axle from a variety of angles since the tubing will flex without difficulty. This is useful when using a variety of motors

to drive a variety of unusual drums.

The drum must be very well centered on the motor axle, but fortunately, this is surprisingly easy to do. Most plastic pill bottles, film cases etc. already have a little nub right on the center of the lid. I assume this is some natural artifact of the process by which they are formed. Just hunt around a bit and use a bottle with this built-in center mark, and you'll have no difficulty here.

Personally, I like to mount the lid from the bottle to the axle so that the bottle can be easily removed and replaced.

The rubbing block shown in figure 6 turned out to be a very handy design. By looping a piece of wool against the Lucite as shown, the block makes excellent contact with the drum. A variety of rubbing materials can be tried by simply slipping them in between the block and the drum. I think that leather or nylon probably provided the best results when used with the film case. To make these experiments easier, use "loose pin" hinges for mounting the rubbing block.

Rather than use steel brushes to collect the charge from the drum, I came up with what I call "riders." These are formed by wrapping a short length of wire around the copper wire conductor coming from the globe. These wires should be loose enough to dangle down onto the drum and "ride" along its surface. Riders have many advantages. They are very tolerant of wobble in the drum. You may be able to change drum types and sizes without adjusting them in any way. You can improve the efficiency of "riders" by coating unusued surfaces with corona dope.

The PVC tube and collecting ball are easily mounted by drilling a tight hole in the 2x4 to accommodate the PVC tubing, by applying a little Silicone glue to the base, and by tapping it into place with a hammer. A large copper wire is run through the tubing as shown and is connected to the collecting ball with a brass screw. The ball, itself, is then mounted with a bead of Silicone glue.

Testing and Operation

Turn on the static generator's motor and allow it to run for 20 to 30 seconds. It takes some time to build up a charge. Next, hold one lead of a Ne2 neon bulb, available at electronics stores for about 49 cents, and bring the other lead near the brass bulb. When the free lead is

nearly touching the bulb, the lamp should flicker or flash. Though the shock from this tiny generator can barely be felt, keep in mind that it takes nearly 90 volts to light the bulb!

Next spread some small, dry, pieces of styrofoam on the top of the ball. By bringing your hand close to the styrofoam you can actually cause them to move mysteriously toward your hands.

Touching this generator is perfectly safe. Under good conditions you should feel and hear a light static "pop" when you touch the fully charged top terminal. If you have trouble feeling the "pop" with your fingers try using your nose. I don't know why, but bringing your nose near the ball brings on a very subtle and strange electric sensation.

With this generator you can do many of the experiments mentioned later including charging up capacitors and energizing spark gaps. So experiment and enjoy.

REMEMBER!

If you are using yourself as ground, as described in the above experiments, you might find that generator performance seems to decrease after several experiments have been performed. What has actually happened is that by repeatedly touching the ball, you have charged yourself up to the same degree of charge as that of the ball, giving the electricity no desire to jump to you! This is simply remedied. Just touch a cold water pipe or other ground from time to time while you experiment.

One minor problem that can pop up is motor speed. Your motor may run too fast. We'll discuss a motor speed control a little later on. Don't worry if the riders hop around a bit. This is usually OK and won't cause problems.

Although a plastic film canister appears in the photos, jars with semi-transparent finishes perform. PVC might also make an exellent drum. Experiment!

A Useful List of Materials for Friction Generators

What follows is a useful list of materials that have a predisposition for taking on a negative or positive charge. By choosing materials that are far apart on this list you can increase the efficiency of a generator.

This list is excerpted from *Nature's Electricity* TAB books No. 2769 and is called "The TriboElectric Series."

POSITIVE CHARGE

Air
Human hands
Asbestos
Glass
Mica
Human hair
Nylon
Wool
Fur
Lead
Silk
Aluminum
Paper

NEUTRAL

Cotton
Steel
Wood
Amber
Sealing Wax
Hard rubber
Nickel, Copper
Brass, Silver
Gold, Platinum
Sulfur
Acetate
Polyester
Styrofoam
Orlon
Saran
Polyurethane
Polyethylene
Polypropylene
Vinyl (PVC)
Silicon
Teflon

NEGATIVE CHARGE

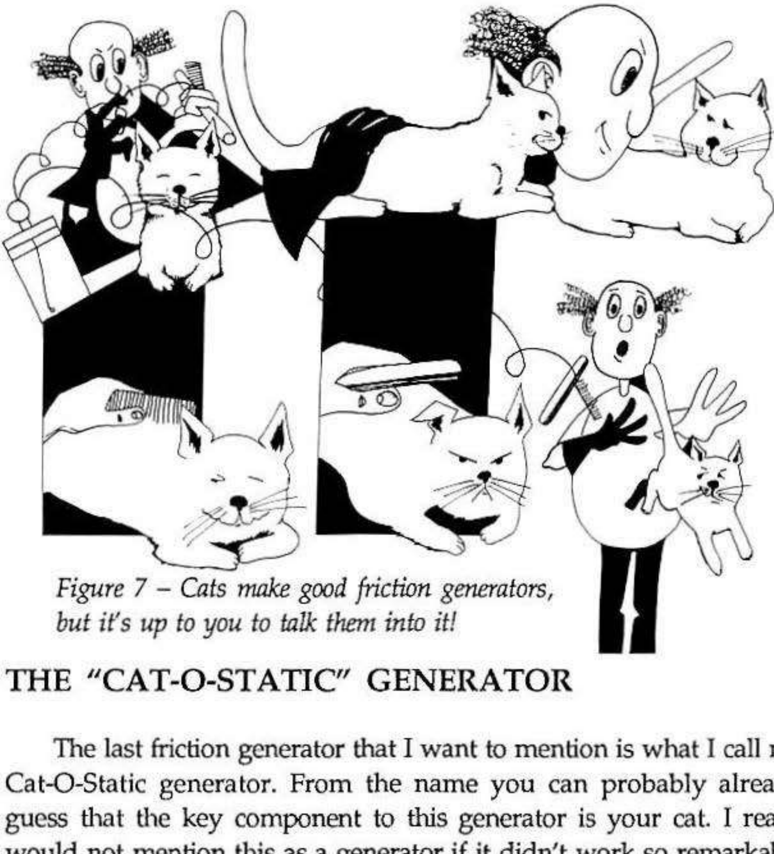


Figure 7 – Cats make good friction generators, but it's up to you to talk them into it!

THE "CAT-O-STATIC" GENERATOR

The last friction generator that I want to mention is what I call my Cat-O-Static generator. From the name you can probably already guess that the key component to this generator is your cat. I really would not mention this as a generator if it didn't work so remarkably well!

For the most part cats enjoy being electrostatic generators, the trick is to make them think they are being petted, and not used as a science experiment. (The cat commandments state somewhere: "Thou shalt allow thyself to be petted only when it suits your purposes and not those of another.")

First, you will need a rubbing material. The very best material I found for this purpose was the artificial leather used in cheap motorcycle gloves. It's actually a type of vinyl. You can secure a pair of these gloves for 5 or 10 dollars at any motorcycle shop. Some are called "man-made leather."

The next thing you will need is a metal flea comb and a length of PVC tubing. You will also need a Leyden jar to store the charge built up by your Cat-o-stat. Leyden jar construction is described in detail later on. The metal flea comb is held at the end of the PVC tubing by a slit cut in the tubing and some glue. A wire is attached from the flea comb to the top of the Leyden jar.

Put a glove on one hand and hold the PVC tubing with the other. Coax you cat into your lap, and tell him wonderful things about himself. This never fails to distract them. Pet him with the glove, and follow the glove with the metal comb to pick up the charge.

With my cat's fur and my particular gloves I am able to build up a charge so large that it will penetrate my vinyl gloves with a strong prickling! However, keep in mind that this type of generator will usually run off and hide before a large Leyden jar can be fully charged. Of course, if you have several cats, use them all to the charge the jar!

AC vs DC Motors and Controls

As we move on to the higher power generators, a little discussion is in order with regards to AC (alternating current) and DC (direct current) motors, and some good ways to control them.

In the generators I've built and discuss here, I have used both AC and DC motors. AC motors have advantages in that usually no external transformers or circuitry are required. They develop plenty of torque – so much so in fact, that you rarely have to worry about stalling the motor. Most AC motors have no brushes or other components to short or wear. They will generally run for years and years, often until the bearings themselves wear out! In general, I prefer using AC motors over DC motors whenever possible.

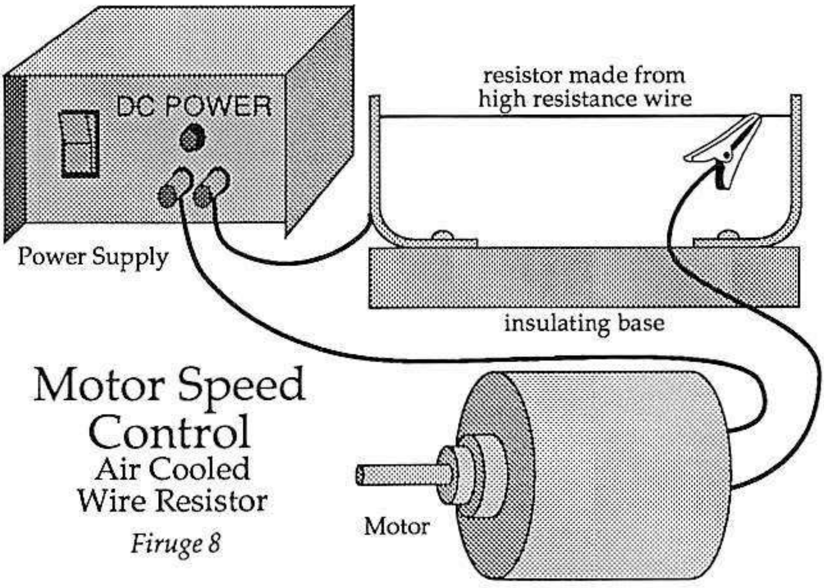
The major shortcoming of an AC motor is low rpm. The high performance Van-De-Graaff-type generators describe below work best at around 5,000 rpm. If the motor runs faster than this, electrons can literally be "blown" off of the carrying belt, and performance suffers. At lower rpm, leakage can impede the build up of high voltage. Since AC motors do not usually develop high rpm, DC motors should be considered for these high performance generators.

Unlike AC motors, DC motors are portable when battery powered and achieve high rpm easily. Keep in mind that a DC motor rated at

6500 rpm may not achieve that speed when driving your device. The rpm rating is usually the maximum no load speed of the motor.

Although not always necessary, you will probably find that you will want a motor with speed control as part of your DC static generator design. A number of dependable methods are shown in figures 8 through 12.

Figure 8 shows a piece of high resistance wire soldered or tied



Motor Speed Control
Air Cooled Wire Resistor
Firuge 8

between two copper posts. One side of the wire is tied to a 12v (or similar) power supply. A wire coming from your motor is attached to an alligator clip which can be moved along the wire to increase or decrease the motor speed. This method works extremely well. However, be aware that the wire can become red hot when supplying current to the motor! Make sure to house it safely.

High resistance wire is easily obtained from a variety of sources. You can use the NiChrome wire that comprises the heating coils in an old toaster, hair dryer, or similar heating device. You can also purchase NiChrome wire from any well-stocked hardware store. Keep in mind that a fairly long piece may be required. Another variation that can be tried is to use a high wattage rheostat, or even the speed control

handle from a "slot car" set.

Figure 9 shows the use of power resistors to slow a DC motor.

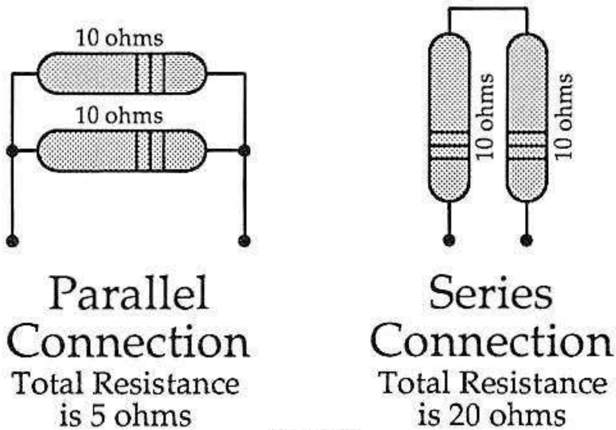


Figure 9

Power resistors are inexpensive, and if you buy a handful of different values you can connect them in parallel or series to get a wide variety of different values. Keep in mind that resistors have two ratings, the power handling capacity measured in Watts, and the resistance measured in Ohms.

An Ohm is a measure of the opposition to current flow. A resistor of 10 Ohms will oppose current flowing through it twice as much as a resistor of five Ohms.

Wattage is simply the amount of power your resistor can handle without being destroyed by overheating. In general, I'd say the higher the wattage rating the better. The Winter's Ring generator shown next required a 25 watt, 10 Ohm resistor, but had to be water cooled to increase its power handling capacity above the 25 watt air cooled rating.

Resistors oppose current flow and in doing so, convert electrical energy into heat. It's normal for them to become very warm. If your resistor gets too hot, its resistance can increase well above its stated value. A change in resistance can cause your motor to run at uneven speeds. You will either need to buy a resistor of a larger wattage, or use some means to cool it such as water (shown and discussed later). As a rule-of-thumb, don't use a resistor of less than 10 watts unless you have a very small or efficient motor.

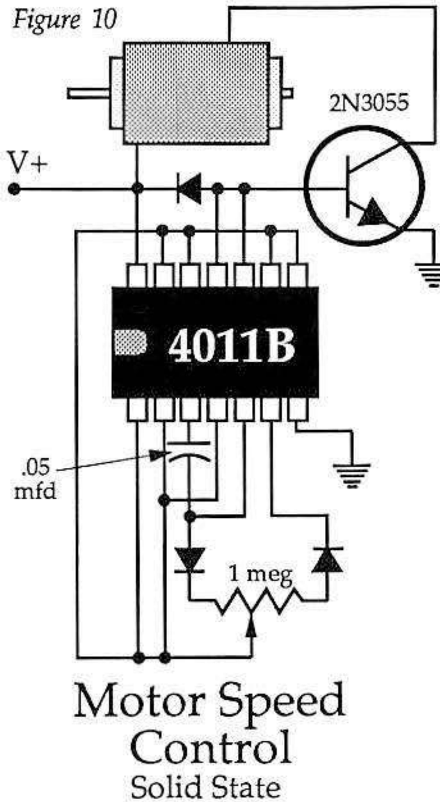


Figure 10 shows a very accurate and stable means of controlling a DC motor. An integrated circuit and power transistor are used to send a stream of pulses to the motor. As the pulse rate increases, the motor speed also increases. By simply turning the potentiometer, you can adjust motor speed at any time. For mid-sized DC motors a very large heat sink or water cooling is required for the transistor.

I have found that DC motors operating at high speeds can behave strangely. Slight variances in the motor's speed can set up an oscillation within the belt being driven. Because one side of the belt is being "pulled" and the other

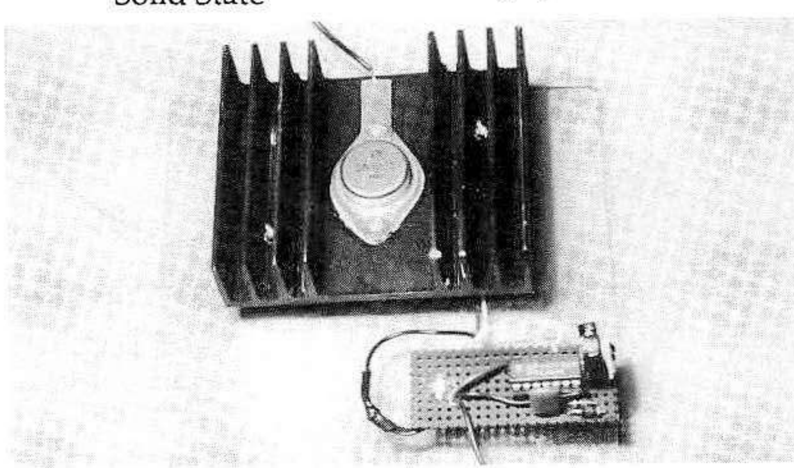


Figure 11 – Solid State Motor Control

is being "pushed", uneven tensions react with the belt's flexibility to produce a "flying" belt that makes only intermittent contact with the rollers or pulleys. This can cause a belt to fly off, bend brushes, or just make a lot of noise. Also, if ball bearings are not used in the rollers, an oscillation can occur among the bushings of the upper roller, the axle, and the belt. All of these problems can be easily solved by using a versatile speed control.

Component Cooling

You may to have to improvise methods of keeping electrical components cool. If you are using a fairly large, high RPM, DC motor which will need sizeable amounts of electrical power, components in the speed control are going to get hot. It may seem a little unorthodox, but water makes a fantastic heat sink for electrical components! Power resistors and even power transistors can be run well beyond ordinary

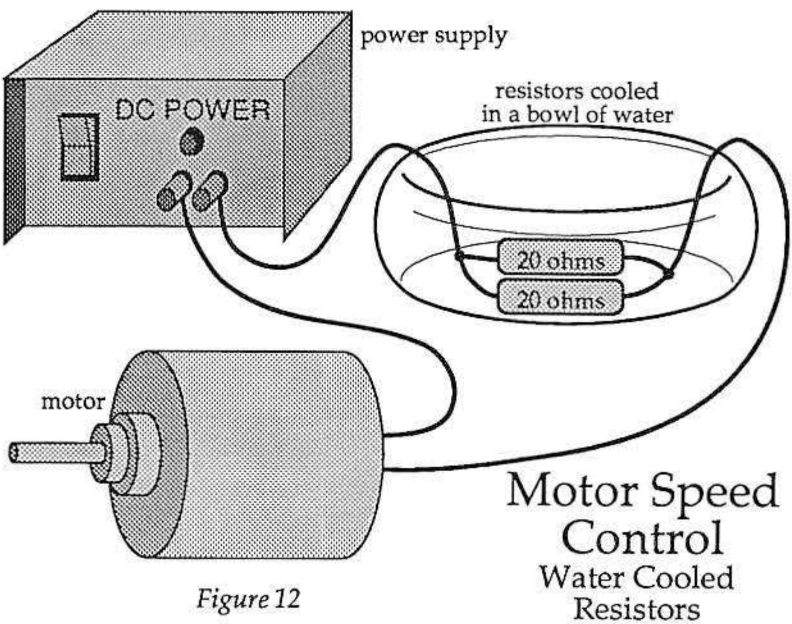


Figure 12

heat sink tolerances when submerged in water. (Figure 12)

Distilled water is a very poor conductor of electricity and will not

short out most components. Tap water is usually OK for resistors, but minerals and other gunk will cloud the water after a short time.

As long as the circuit is submerged in water, you know that the temperature of the water must be below 212 degrees Fahrenheit (100 Celsius) at normal atmospheric pressures. Above this temperature the water will boil away. Many electronic components work quite well up to 212 degrees. Just remember to add a little water now and then to compensate for evaporation.

AN EXTERNAL VAN DE GRAAFF USING "WINTER'S RING"

If you built the last generator described, you know that I wasn't exaggerating when I said you could get 3500 volts (or more) from an old film canister. Although interesting, this simple rotostatic generator won't keep you satisfied for long. There are higher voltages to conquer! So let's move on to the next type of generator and try for 10,000 volts (and possibly several times that amount) from a rubber band.

I call the following generator an "external" generator because all of the components of the generator have been mounted externally in such a way as to make construction and experimental modifications fast and easy. Since all of the workings are exposed, this generator is great for the experimenter who wants to quickly try different materials and configurations in developing his own generator design, or for someone who wants to whip together a simple generator to demonstrate.

The high voltage terminal of this generator consists of a metal ring, or toroid, of exceptional efficiency. I call it a "Winter's Ring" although such rings have been traditionally made of wood. They're rarely used anymore. As with other parts of this generator, the Winter's Ring may be quickly replaced by a more traditional spherical-shaped terminal or many others you might wish to try. Why not keep several on hand for demonstration?

Despite the fact that, as we've discussed, electrostatic principles have been well know for thousands of years, it was not until as recently as 1928 that a truly practical machine for generating high static voltages was perfected. Robert J. Van de Graaff, a young Rhodes

scholar working at Princeton, designed his first machine to generate the high potential needed to power a particle accelerator to bombard atomic nuclei as part of his experiments in nuclear research.

Although it can be difficult, it is not impossible for the home experimenter to make his own atom smasher! A Van de Graaff generator such as described here is an integral part of such an apparatus. If you are interested in taking on a project of epic proportions, find a copy *"The Amateur Scientist"* by C. L. Stong which is now out of print and very difficult to find, but worth the effort. Or write for similar information from Information Unlimited, P. O. Box 716, Amherst NH 03031.

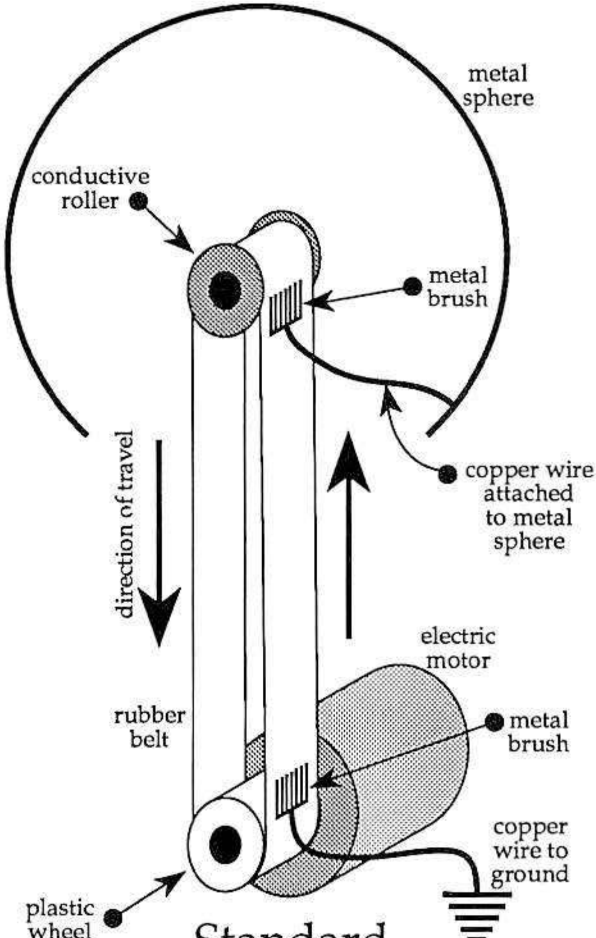
The Van de Graaff is so simple and obvious in design that it amazes me that is wasn't developed sooner. I have always thought that this is a good example of just how inventions don't have to be extremely complex to have a significant impact on society. How many other simple devices are there waiting to be designed and built? It could be you that dramatically changes the world!

The easiest way to understand the Van de Graaff is to refer to the schematic diagram in figure 13. A Van de Graaff generator consists of a belt, two pulleys, a motor, brushes, a high and a low potential terminals.

In newer machines the bottom pulley is plastic while older machines used an insulator covered by wool or similar rubbing material. The top pulley must be of a conductive material such as metal or even wood which is not a good insulator at high voltages.

When the machine is in operation, a small motor attached to the bottom pulley drives the belt that is lightly stretched between the pulleys. Friction occurs between the surfaces of the belt and the plastic wheel, putting an electrostatic charge on the belt. The charge is carried by the belt toward the upper terminal. A grounded wire brush makes contact with the lower portion of the belt and bleeds off some of the negative charge. The brush at the top of the belt accepts the positive charge remaining and distributes it on the high potential terminal. (Note: It is possible to make a Van de Graaff generator that develops a negative charge on the high potential terminal.)

As the belt moves, charge builds up on the high potential terminal. Theoretically, this charge could increase forever. However, leakage into the air from the upper terminal limits the maximum potential to



Standard
Van de Graaff Generator
Schematic Diagram
Figure 13

about 50 to 100 thousand volts typically.

A simple way to calculate the theoretical maximum for a "perfect" spherical top potential is to figure a voltage 70,000 times the smallest radius of the curvature of the high potential terminal. For example– most spheres are sold with reference to their diameter. For a 12 inch diameter sphere, we divide 12 by 2 to get the radius, or 6 inches. We

multiply 6 by 70,000 to get a theoretical voltage of 420,000 volts.

Because your terminal will never be a perfect sphere, and because there will be leakage into the atmosphere, theoretical voltages won't be reached. You might find these ball-park calculations interesting, nonetheless.

A photograph of my external Van De Graaff and its schematic are shown in figures 14 and 15. I found this to be an extremely simple and inexpensive design. In operation it will produce a reliable voltage in the range of 10 to 30 thousand volts using an ordinary rubber band. It will produce a solid and exhilarating "pop" when it discharges to your hand. It can throw sparks to ground more than an inch in length. Neon bulbs such as a Ne2 will glow brightly and continuously when near the generator. A blue corona glow can be readily observed from the collecting brushes in a darkened room once your eyes have adjusted to the dark. Negative and positive corona can also be identified by their appearance using this device as discussed later.

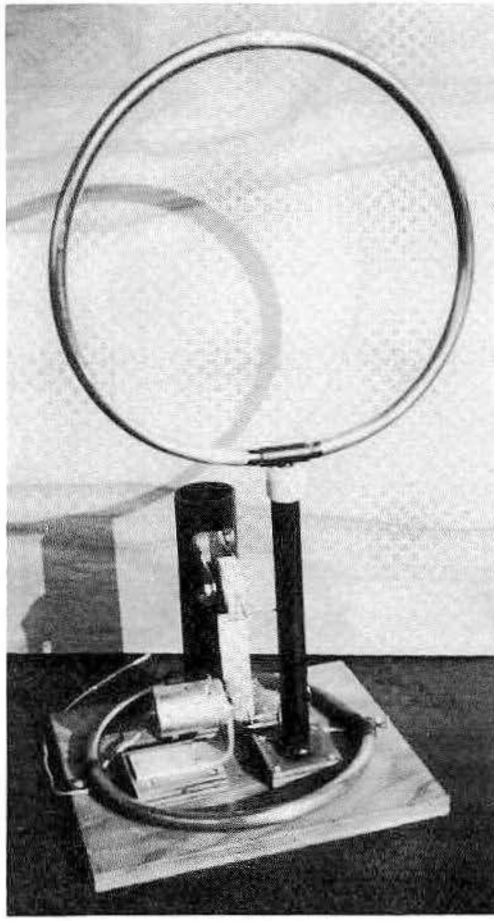
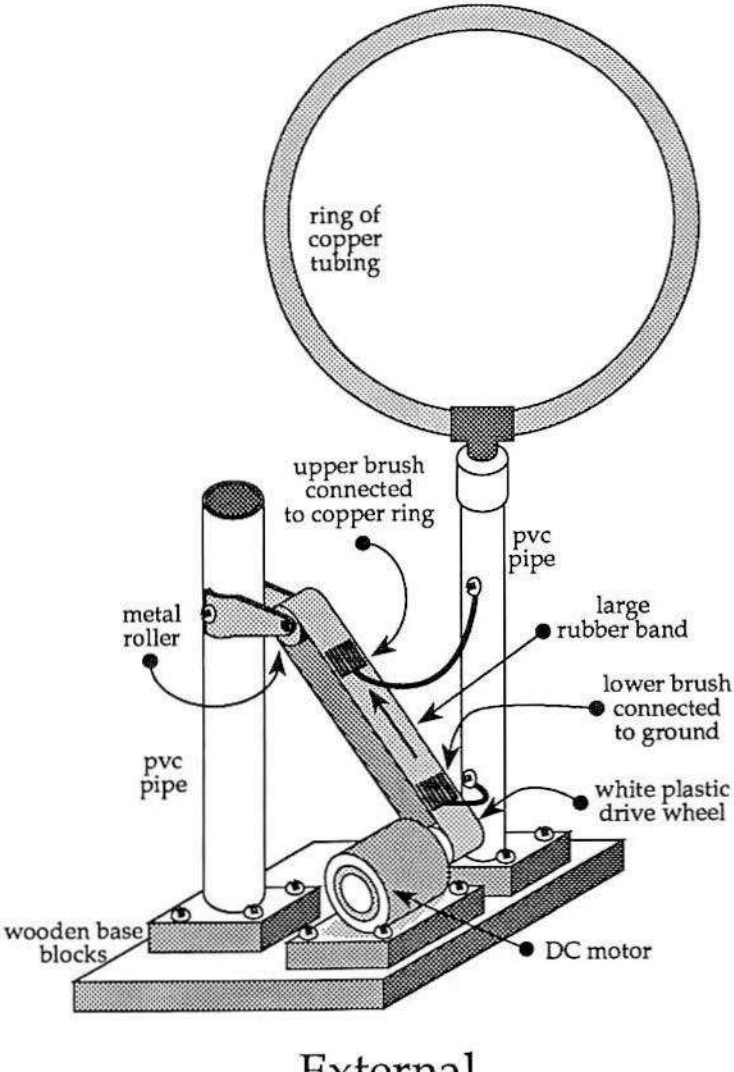


Figure 14 – External Van de Graaff Generator

The external Van De Graaff shown has some minor performance limitations due to the relatively high friction of the top wheel (no ball bearings) and excessive flexing of the rubber band. A rubber band should be used as a belt only for demonstration purposes. For more



External
Van de Graaff Generator

Figure 15

serious experimenting, replace the belt with a less flexible belt such as made from a bicycle inner tube or, ideally, neoprene. Also, without ball bearings, the top wheel required occasional lubrication that frequently brought about the risk of oil contamination. Except for these minor problems, this generator has proven to be an excellent and reliable performer. It still remains the most easily modified and observed of the Van de Graaff designs I'll describe.

The construction of the external Van De Graaff is so simple and straightforward that little description is required outside of the drawing. A few tricks can simplify and improve construction.

An easy way to get your motor, roller and belt in alignment is to run your generator while holding the motor with your hand, experimenting until you find the right position for it. If your belt slips off, shift the motor slightly to change its attack or grip on the belt.

When connecting a belt between two rollers in any Van De Graaff type generator, it is natural to assume that pulleys should have flanges on their edges to provide a groove in which the belt will run preventing it from slipping off the driving wheel. Surprisingly enough, the belt will have a tendency to stay centered on the pulleys even when they are somewhat out of alignment! I assume this has something to do with the way the pressures change in the belt as it approaches the edge of a pulley. You may find that a small "hump" in the drive wheel can even be helpful at high rpm. Once aligned, you should have no problems at all with belts slipping off.

Use the largest diameter of copper tubing that you conveniently can for the top terminal. The problem is that when larger diameter copper tubing is bent into small diameter circles, undesireable ripples form. Larger gauge tubing must be bent into larger diameter circles forcing you to compromise between size and efficiency.

When soldering the two ends of the copper tube into the "T" connector, first clean them with extra fine steel wool, then coat (tin) them with a little solder before inserting them. This will give an exceptionally strong and smooth bond. You can use any ordinary propane torch for heating and soldering the tube.

If you use the same type of brushes as shown in the drawing, it might be tempting to shorten the copper wires leading to them from the PVC tubing or otherwise alter this mounting. Don't do it! It is the flexibility in these long copper wires that provides the "spring"

needed to keep the brushes flat against the belt.

The plastic bottom pulley is simply one of the white plastic wheels used on cheap furniture casters. It is attached to the motor shaft by carefully drilling out the wheel's center hole to a size slightly smaller than the diameter of the motor axle. You then apply a few drops of super glue to the axle and press or tap the wheel into place.

If the hole in the wheel is larger than the diameter of the axle, glue progressively larger diameter pieces of rubber tubing to the motor axle until the wheel fits snugly in place.

One last note: Since your top terminal is copper which quickly tarnishes, you might want to apply a little Silicone cleaner/protectant such as that sold for cleaning chrome automotive parts. This will keep your top terminal bright and shiny at all times. It also seems to limit leakage and produce an interesting double "pop" when touched.

The Evils of Oil

The only major problem that I encountered in building and operating Van De Graaff generators regardless of design is oil contamination. Since a Van De Graaff generator relies on friction between the plastic wheel and rubber belt to produce a charge, you can imagine the devastating effect oil or any lubricant can have on belt performance. Even the oil from your fingers can reduce the charge carried by the belt. Handle your belts sparingly, and hold them only from the outside edges as you might a record album.

The worst lubricant is a petroleum-based oil such as used to lubricate motor axles and bearings. Angular momentum from the motor axle can actually pull a drop of oil all the way along the axle, along the side of a wheel, and out onto a belt. *Therefore, **Do not oil your motor or bearings excessively.***

If you want a graphic demonstration of this effect, place a drop of fast drying super glue on your motor's axle. Before it has a chance to dry, run your motor for several seconds. If your motor is like mine, you will have a little trail of super glue from the axle to the outside of the wheel where it will form a little blob.

Once your belt and wheels are contaminated, they can be very difficult to clean. The best way to clean the belt is not to clean it all, but to throw it in the trash and get another belt.

The conductive metal top roller can be cleaned with a residue-free cleaner like ammonia, followed by a light sanding with extra fine sand paper and then by another ammonia cleaning.

Cleaning the plastic wheel is the most difficult. The plastic wheel usually builds up a static charge of its own during the time the generator is run. This charge seems to act like a sponge for oil! The only way I have found to remove it is it by attaching a wire to ground and running the motor while dragging the wire along the outside of the wheel. After discharging the pulley in this way, ground a piece of metallic sand paper and again run the motor while sanding away some of the outside of the wheel. This is accompanied with or followed by ammonia cleanings. Other solvents may work, but watch out for those that may dissolve the plastic. I realize this procedure may sound extreme, but I have even tried soaking the plastic wheels in industrial degreasers not available to the general public and have had no luck at removing this oil in any other fashion. If you are careful in your use of oil you will never encounter this problem.

A Few Words On Brushes

In both of the Van De Graaff generator designs described in this book, I used a simple tuft of wire soldered to the end of a thicker solid copper wire spring which provides the force necessary to keep the brush riding firmly against the belt. By far the biggest problem you are likely to encounter will be in keeping the brush riding solidly on the belt. If your brushes are not well placed, or your belt has undue flexibility, the brushes may have to be readjusted frequently.

Many configurations, some very elaborate, have been tried in an attempt to perfect a fool-proof brush assembly. I haven't found one yet. You may want to try a hinge, a spring, a piece of metal screen, or even a conductive rubber or foam such as those use to package integrated circuits. In designing a brush assembly, keep in mind that, ideally, it should be comprised of many fine points like the ends of wires because the density of electrons in a fine point is higher and electron transfer is more likely. Nevertheless I have had very good luck with non-pointed objects such as conductive foams. Most texts, and my own experience has shown that a good old tuft of wire usually wins out, but, as mentioned, this is not a perfect solution to the

problem. So, experiment. And have fun!

A Few Words On Belts

A good belt can be made from virtually any insulating material. Rayon, Dacron, rubber, paper, silk, plastic and even ordinary cloth have been used with success. Wear is probably the most important factor to consider in choosing a material. Rubber, for instance, rots in my home town due to the ozone contained in the smog here. Cloth will fray at high speed, although I have coated cloth with an extremely thin coating of Silicone rubber and have made good belts. Neoprene, joined with a diagonal splice is a long-time favorite.

In my opinion, the easiest all-around belt is made from an old bicycle inner tube, or even better, the rubber "liner" that covers the heads of spokes under the rim. One of these belts can be carefully spliced with inner tube cement from a tire patch kit. Even a little "Super Glue" will work if the splice is clamped.

In fabricating a belt also remember that the wider the belt, the faster a charge accumulates (within reason). And, you may also want to give a little thought to the noise generated by certain materials. At 5000 rpm a poorly made belt will make considerable noise.

One last belt option is to purchase a ready made belt from a scientific supply house such as Analytical Scientific, Post Box 675, Helotes, TX 78023. Such companies can often supply many different sizes and types of belts. I would suggest ordering the thickest, and strongest belt offered for a home-made generator. I find the price of commercial belts a bit too expensive for my bank account, but you might find their prices more acceptable depending on your project.

THE HIGH POWER "CLASSIC" VAN DE GRAAFF

Although these voltages are impressive, keep in mind that the classic Van De Graaff will easily produce 60 to 100 thousand volts or more and is only slightly more difficult to build.

The classic design for the Van De Graaff is shown in photograph 16. The one minor concession I made in my design was to use two stainless steel bowls for the high potential collector instead of the traditional sphere. I did this simply because I could not readily find a

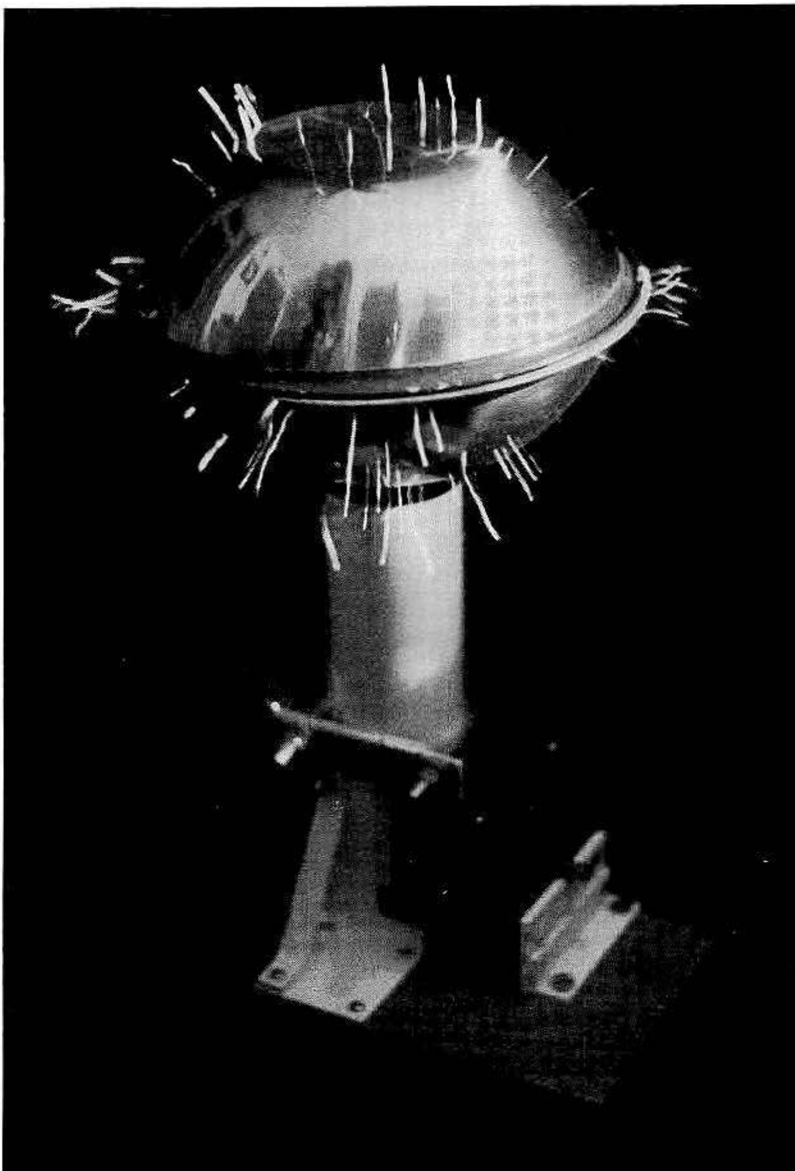


Figure 16 – Classic Van de Graaff Generator in Operation – This long-exposure photograph clearly shows the remarkable energy generated by this simple device.

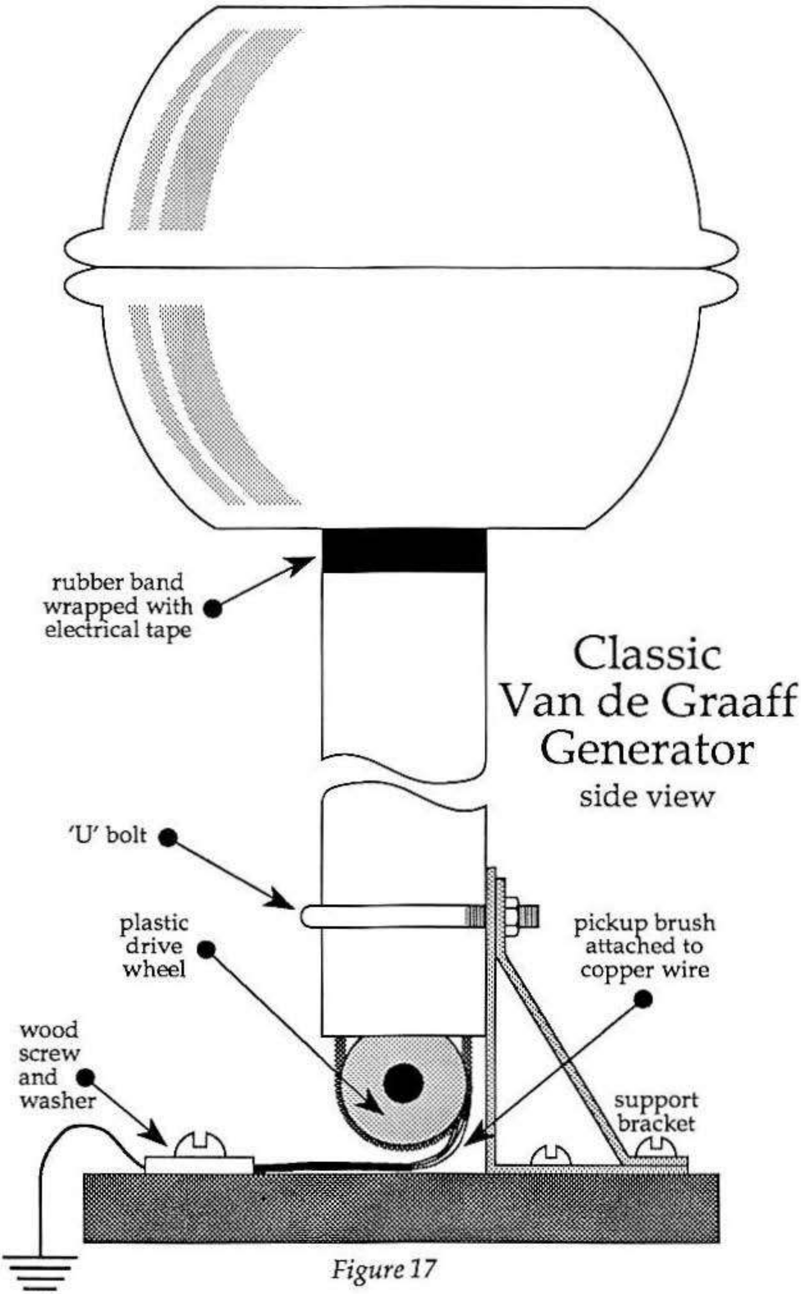

rubber band wrapped with electrical tape
Classic Van de Graaff Generator
side view
'U' bolt
plastic drive wheel
pickup brush attached to copper wire
wood screw and washer
support bracket

Figure 17

sphere of the proper dimensions. Besides, two bowls allow easy access to the top roller and brushes, and I wanted to test my hunch that almost as much power could be obtained from the bowls if the edges were heavily doped and insulated as could be obtained from a traditional spherical terminal.

All of the experiments to be described can be performed with this unit. It is an all-around solid machine and is fun to operate. If you plan to build only one generator from this book, and are wondering which generator to select, this machine is the best all-around performer. If carefully built, this design will exceed a voltage of 100,000 volts. It will arc thick, blue sparks well over four inches to an outstretched hand and deliver an invigorating, if not slightly uncomfortable, shock.

This generator is capable of charging up a person's body to a high voltage. It makes possible many experiments such as causing a person's hair to stand on end, or the rapid charging of large capacitors. The device will even produce an ominous "crackling" as your hand approaches the high potential terminal.

By standing on a large plastic insulator such as an overturned detergent bucket, a friend of mine was able to charge her body to such a high potential that her hands would "crackle" any time she pointed to a person nearby in the room. I think a physics or chemistry teacher would have little trouble keeping his/her students attention if the mere pointing of their hands produced this ominous cracking!

Though I am certainly not recommending the following approach, this generator was also inadvertently useful in training a dog in a single lesson not to jump on people. My dog, Merfi, had the bad habit of greeting people by jumping all over them. Nothing, it seemed, could discourage this behavior. One afternoon some friends and I were standing around a completed Van De Graaff and commenting on what an unusually large charge we had managed to bestow upon a person. Suddenly Merfi bounded into the shop. Despite our pleas, Merfi shot across the shop with his usual enthusiasm and leapt nose first into my highly charged friend, no doubt, intending to bestow upon him his traditional greeting.

We could do nothing but watch as a large blue spark jumped to Merfi's moist, waiting nose. Merfi stumbled back, temporarily lost control of his bladder, and then slunk out the door. A few moments later everyone was petting and reassuring Merfi, yet, to this day we

have had virtually no problems with Merfi's traditional greetings. He still eyes the friend from whom he received the shock with suspicion. And with good reason!

I suppose it is needless to say that it is wise to keep any and all pets a safe distance from your experiments. As with the external Van De Graaff generator, very little description outside of the drawings is required for constructing the classic Van De Graaff design.

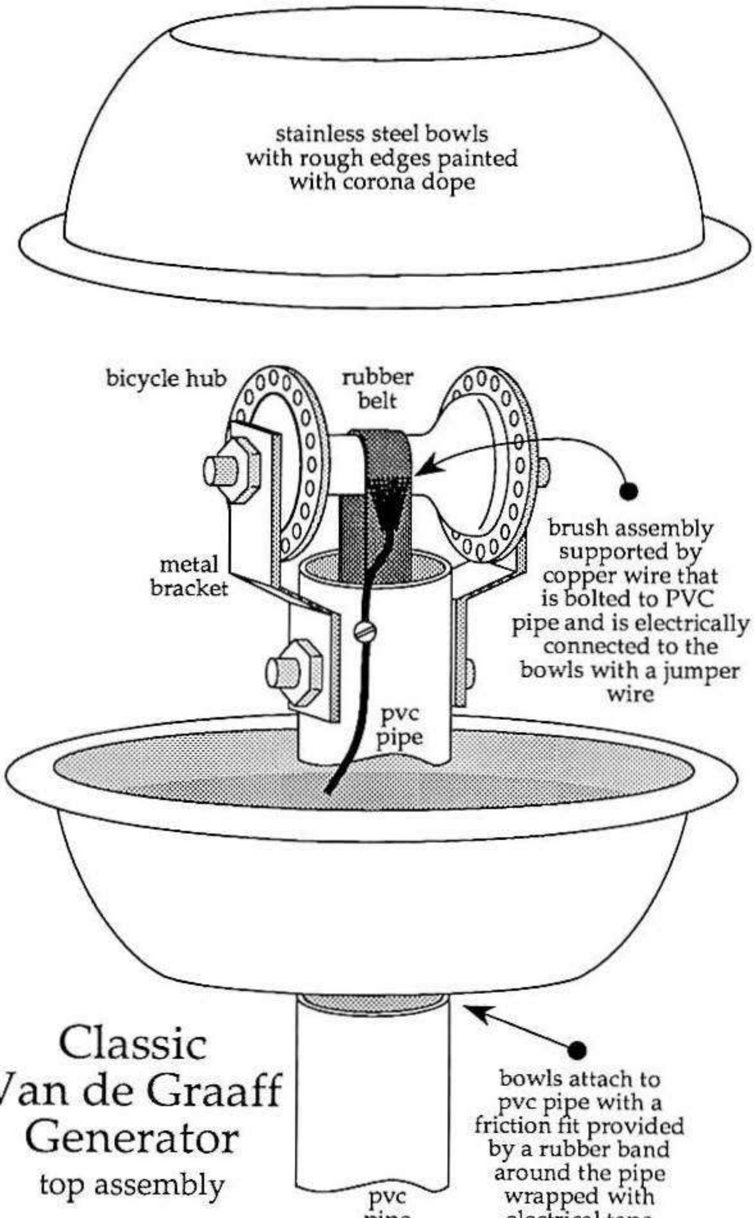
Figure 18 - "Merfi" – (An accidental electrostatic participant)

Things to keep in mind

The edges of the bowls are relatively sharp, even though the edges have been folded over. To prevent the charge from leaking through these sharp edges, they are coated with a special paint called "corona dope" which can be purchased in most T.V. and well-stocked electronic stores. It is available in both spray and brush-on forms. Corona dope has a high dielectric strength, and will prevent a charge from leaking off into the air. It can be used on any spots suspected of leakage on any of your high voltage projects. Keep in mind that the thicker the coating of corona dope, the better it will shield. I used around eight thick coats on my Van De Graaff and should have used more. Sparks fly right through it!

As with the last generator, the lower pulley is a white plastic wheel taken from an inexpensive furniture caster. It was mounted in the same way as was done in the external Van de Graaff.

The upper pulley is the front hub of a 10 speed bicycle wheel. I tried several different methods to reduce the friction of the hub bearings to make it turn more freely. I tried a variety of lighter oils and even



Classic
Van de Graaff
Generator
top assembly

Figure 19

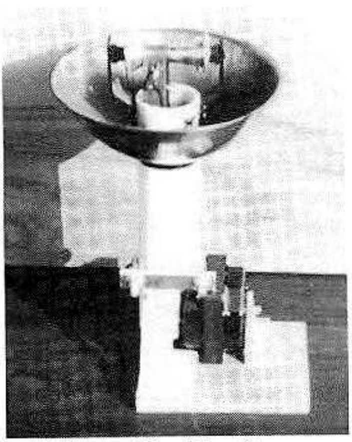


Figure 20 – Top Open

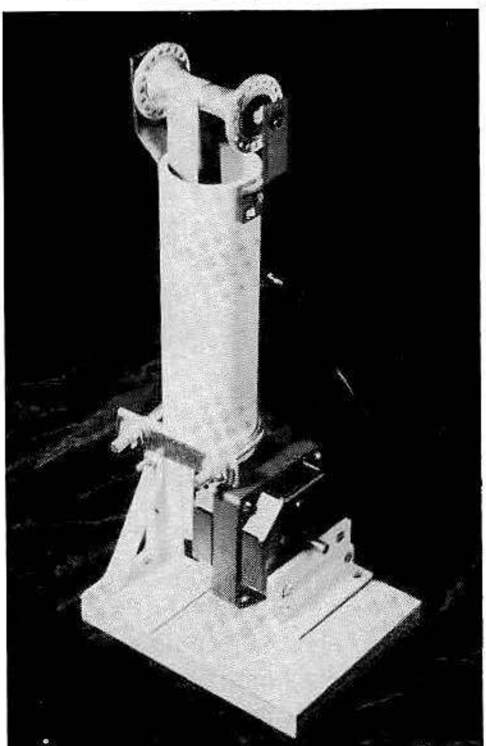


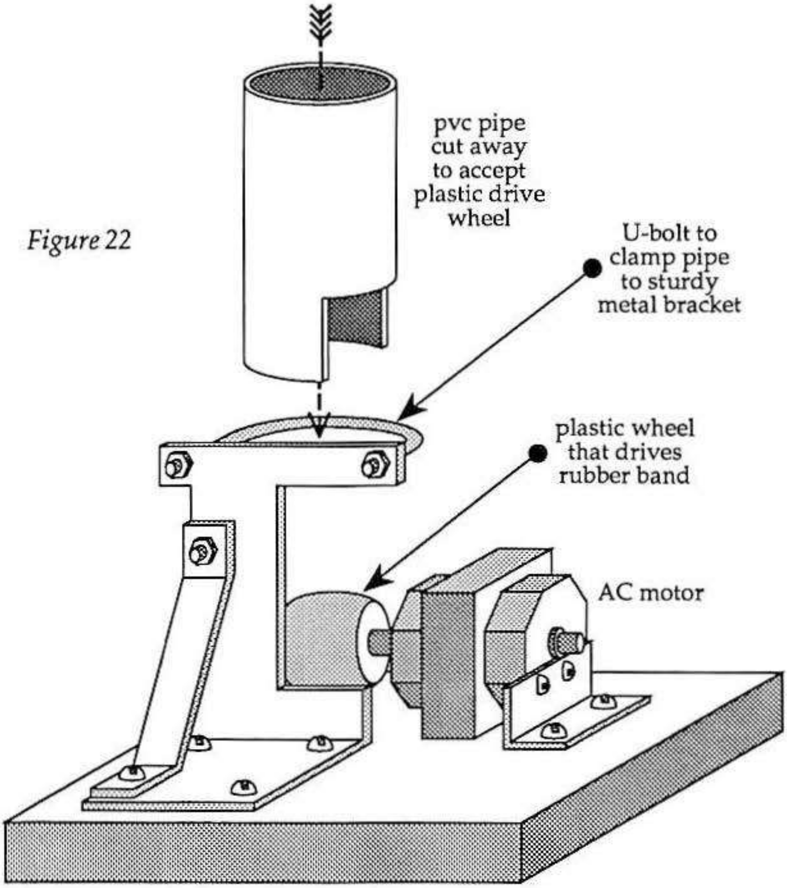
Figure 21 – Terminal Removed

removed the rubber covers that protect the ball bearings from dirt contamination. I found that lighter oil works well, but because of the risk of oil contamination as discussed earlier, I ended up using grease. Removing the covers also helps, but when the generator is running and the roller is spinning, a sizable charge builds up on its surface, and every dust particle in the area is attracted to it! Although you may want to experiment, I have come to the conclusion that the hub should be left pretty much as it is when it comes off the bike.

The two top bowls can be hinged together from the inside with a wide strip of black tape, or can be bolted together by some nylon screws through the lip. Keep in mind that you want the surface of these bowls to remain as smooth as possible to prevent electrons from leaking off. Don't use metal hinges or any sharp objects in attaching them.

The main body tube is fabricated from three-inch diameter PVC drain pipe. (Remember that acrylic or phenolic pipe might be superior to

Figure 22



Classic Van de Graaff Generator
bottom assembly

PVC.) A slot is cut into the lower portion of the tube to allow the motor and plastic drive wheel to be inserted through wall. The PVC pipe is supported by a metal L-bracket and a U-bolt. Depending on the size of your motor, you may want to cut a notch into one side of the L-bracket to provide enough clearance for the motor to fully enter the bottom of the tube. Since this "L" bracket will support your whole generator, make sure it is sturdy and of a heavy gauge. You may even wish to add a metal brace as I did to increase rigidity.

When you have completed this generator, you will be able to perform any of the experiments that follow. This easy-to-build, high performance generator is a very exciting machine to own!

AN EXTREMELY HIGH POWER VAN DE GRAAFF

Before we move on to other types of static generators, I'd like to briefly describe one of the highest performance Van De Graaff generators I have ever seen. Shown in figure 24 is a design for an extremely high power Van De Graaff generator. I have not constructed this unit. I am providing details on this machine should you want to explore machines beyond the limits of my humble designs. This schematic will provide the essential design details.

At maximum efficiency this design could generate voltages exceeding 1,000,000 volts without using an auxiliary storage capacitor!

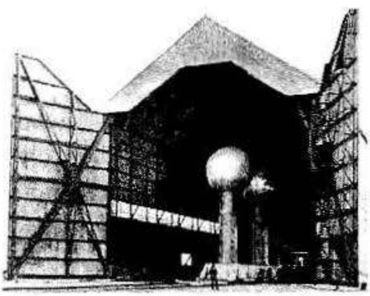
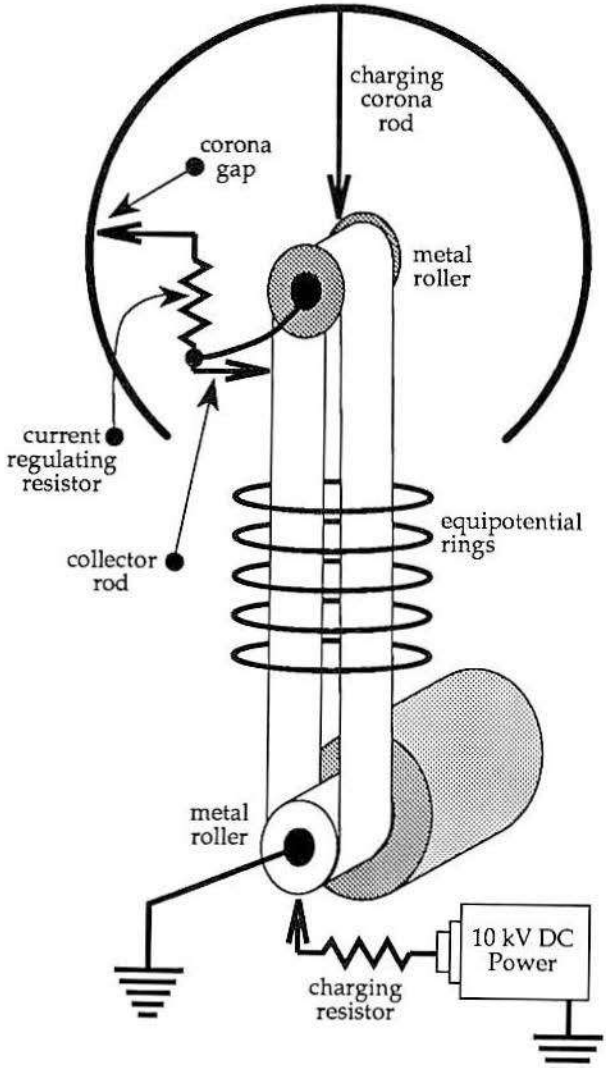


Figure 23 – Ten million volt Van de Graaff generators were built in the 1930's. One generator here is negatively charged, and the other is positive. Generators of this size are not recommended as a first project. (Perhaps not even as a second! ...but call me if you build one!)

Voltages of this order can be dangerous, possibly lethal. This is not a toy and should only be constructed by a serious and cautious experimenter. Because of its high output, I think this unit would make an outstanding laboratory power source for a homemade atom smasher.

The high power unit uses an external high voltage power supply to "spray" an initial charge on the rubber belt. Notice in the schematic that the ends of the spray wires are pointed. A rectified high voltage source between 5,000 to 10,000 volts is ideal. For low cost and ease of assembly you may want to try using an automotive coil as a transformer. For details see Lindsay Publications *"Build a 40,000 Volt Induction Coil."* (Written by an author who is generally a good sort.)

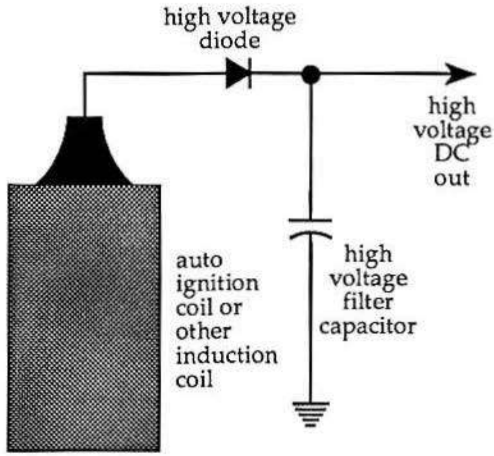
In this design, both top and bottom rollers are metal. The top roller itself is insulated from the high potential sphere. Charge is sprayed



Van de Graaff Generator
high power configuration
using external excitation
(schematic diagram)

Figure 24

Figure 25



Induction Coil Exciter for Van de Graaf Generator

output must be recitified
and filtered

onto the carrying belt as it passes through the corona discharge between the high voltage power supply and the lower roller which is grounded. A second set of points located just inside the upper high potential terminal picks up the charge and conducts it to the upper pulley. Once highly charged, current flows to the high potential terminal through the current regulating resistor. This configuration can also include a corona gap as shown near the inside surface of the high potential terminal.

An additional set of spray points, labeled "charging corona rod" on drawing, connect directly to the high potential terminal and are situated directly above the pulley.

According to *The Amateur Scientist*, *"The difference in potential between the upper pulley, made 'live' by the voltage drop across the current regulating resistor and corona gap, and the high-voltage terminal causes these points to 'spray a charge of opposite sign onto the downward run of the belt.' "*

The value of the current-regulating resistor can be computed roughly by Ohm's law. In small machines it is usually on the order of

40 megOhms.

Optimum belt speed for a high power unit is between 4,000 and 6,000 feet per minute. Most high power units use belts made from rubberized fabric.

If your design is to exceed 200,000 volts, charge distribution along the insulating column becomes important. Machines using belts more than four inches wide should be equipped with equipotential rings as shown spaced every two inches.

A large Van De Graaff generator intended to reach the million volt range is often sealed in a steel tank containing inert gases such as carbon dioxide and kept at many atmospheres of pressure. Keeping the gases at high pressure serves to increase their insulating properties and improves both the voltage and current output of the generator.

Owning a generator of this size would be incredible!

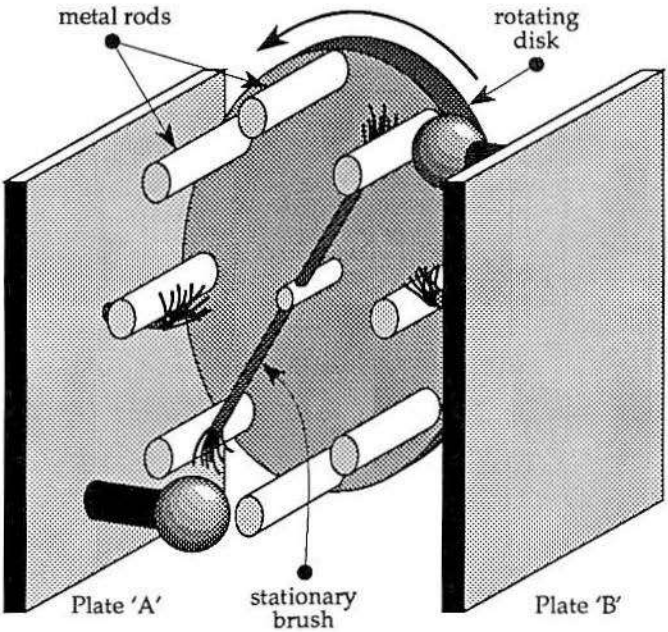
INDUCTIVE ELECTROSTATIC GENERATORS

Wouldn't it be wonderful to have a generator that could produce almost 90,000 volts while being virtually immune to changes in humidity? What if that same generator could be run extensively without concern for wear or maintenance? What if the same generator could be "daisy chained" to other generators to increase their output? What if it could be run as a motor, operating on electrostatic charges, just as a common D.C. generator can also by run as a motor? Well, what we would certainly have is a Dirod generator.

The Dirod generator is another invention of Mr. A. D. Moore. The Dirod gets its name from the main components of the generator: a high grade Plexiglas disk and a series of metal rods. "Dirod" is short for disk and rods. Its operation is most easily understood by observing a schematic representation of its workings.

Figure 26 shows a schematic of a basic Dirod generator. A number of metal rods are attached to an insulating disk (Lucite, glass, plastic, etc.) which is mounted on a bearing that allows it to rotate. In the center of the disk is an axle which is stationary, and attached to this axle is a wire with two brush ends as shown. As the disk rotates, each pair of metal rods is momentarily electrically connected to the stationary brushes as the rods pass by them.

Outside of the wheel we have two smooth metal plates each with



Induction Generator
schematic diagram

Figure 26

an electrode attached as shown and each having a pair of metal brushes as well. Positive and negative charges will form on these plates in the following manner. When the wheel begins its rotation, plate A and plate B will have similar amounts of negative and positive charges – similar, but of course, not exactly the same! Let's say that plate B has a slightly negative charge, and plate A has a slightly positive charge. Now, as a metal rod moves by the electrode from plate A, it is momentarily connected to the rod moving past the electrode from plate B, connected by the stationary brushes from the center axle as shown in figure 27a. At this point, since plate B has a slightly negative charge, the positive charges in the two bars rush into the bar closest to plate B (negative and positive charges attract), and the negative charges rush into the bar closest to plate A. This is comparable to one electrophorus charging the other without having them

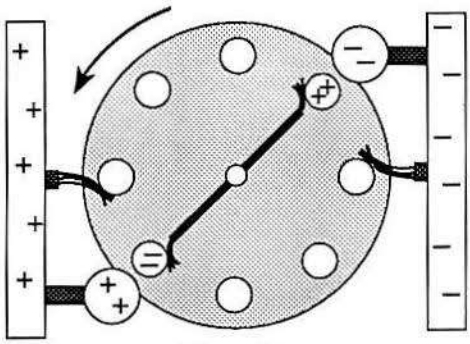


Figure 27a

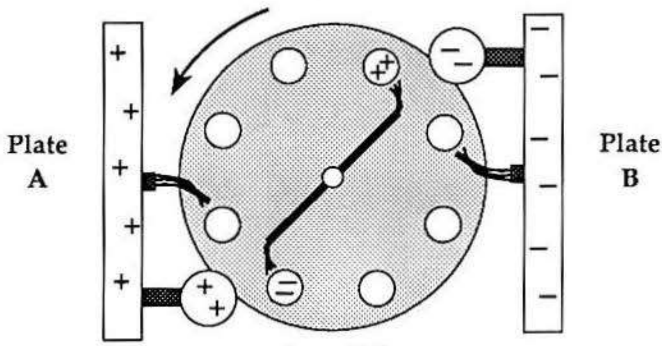


Figure 27b

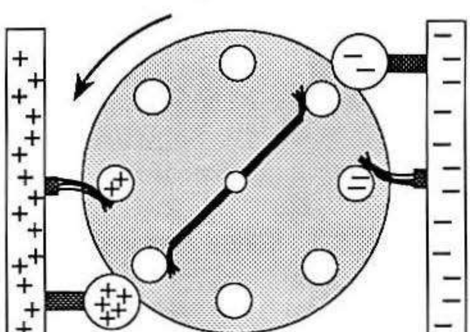


Figure 27c

Induction Generator Operation

actually touch.

As the disk continues to rotate, the two bars move past the brushes and break electrical contact. Now we have one bar with a mostly positive charge and one with a mostly negative charge. Figure 27b

As the bars continue to revolve around to the opposite plate, they briefly make a connection with the brushes from that opposite plate and bestow upon that plate their charge. Figure 27c. Now the plate has an even higher charge than it did originally. It charges the next rod passing by it even more forcefully. In this fashion the plates rapidly build up a larger and larger charge.

When you consider how fast these rods can be spun, and how fast these charges double, you realize how quickly this generator can produce high voltage!

To be a little more technical in describing the difference between our previous friction generators and an induction generator of this type, remember that friction generators charge by contact between two bodies and by the sharing of electrons from the resulting contact. Inductive generators make no demand on free electrons, but on the field they produce. This field causes electrons in the charging material to veer from their orbits. This displacement sets up or induces a charge in the formerly uncharged material. The series of figures 27a through 27c show not only how the machine moves but also how charges are built up during each step of the charging process described.

It is important to understand these simple principles of induction since they are critical to understanding and building the electrostatic motors that follow.

It is interesting to note that the Dirod generator is virtually the same as the world's first electric motor known as the "Franklin" motor for its inventor, Benjamin Franklin, and discussed later on.

Construction of the Dirod Generator

Construction of the Dirod generator is, again, straightforward and simple when viewing the drawings. Keep in mind that the metal rods can be mounted horizontally as shown or vertically, radiating out from the center. Vertical mounting is much trickier. However it is much less stressful on the Lucite disk allowing higher rotational speed to be achieved.

Also very important in achieving maximum voltages is a corona shield which is not shown in the drawing. A corona shield can be fabricated simply by placing a small sheet of Plexiglas between the metal spheres and the rotating rods. I would suggest that you first try your generator without a corona shield, and then with. If your design is optimum, your voltages will increase with the shield.

Because the brushes in this type of design can really take a beating I strongly suggest using a conductive foam such as the foam integrated circuits are packaged in or a conductive rubber brush. If forced to use a metal brush, use a metal that is very springy.

I built an induction generator by modifying the Franklin motor shown later on. By adding brushes and two stainless steel collectors to the Franklin motor, I had both an electrostatic motor and generator! Although I plan to build a much larger, more traditional Dirod machine, this small motor/generator still holds my fascination and continues to teach me the principles I will need to employ in devising the larger unit.

MEASURING VOLTAGES AND POLARITY

WARNING: As mentioned before, the electrostatic voltages produced by the generators in this text are generally safe for the experimenter even should he be accidentally shocked. The operation of the following devices is described for use with electrostatic devices. Should you choose to measure the voltage of other devices, more stringent safety precautions should be taken. Use extreme caution at all times.

Information in this chapter is useful not only in the field of electrostatics, but can also be valuable to those who work with Tesla coils, Oudin coils, induction coils, or other high voltage power generators. One of the most surprisingly difficult things to do with a high voltage is to accurately measure it. I was frustrated to find that text after text said simply that measurement of high voltages was impossible for the amateur. As a result of experimentation and having studied the writings of extraordinary experimenters such as Professor A.D. Moore, I can show you several methods of measuring high voltage that seem quite dependable and accurate. You can also use one of several means to determine the polarity of a high DC voltage – something which is rarely mentioned in any text.

Finding Polarity and Simple Voltage

There are several very simple means for determining the polarity of a high potential. The first, and by far the most sensitive is an FET based "electroscope." Figure 45 shows an electroscope of my own design. The device is simple to assemble and is shown in both schematic and component layout forms. The device works extremely well.

I highly recommend that you build one of these. It can show you the polarity of both very high voltages as well as low electrostatic

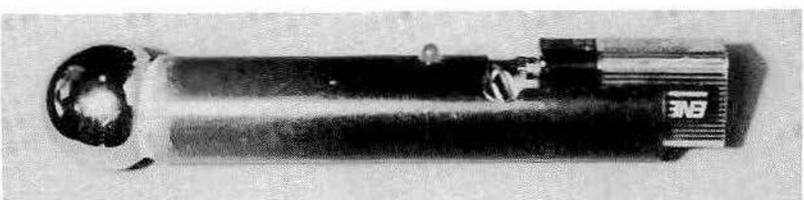
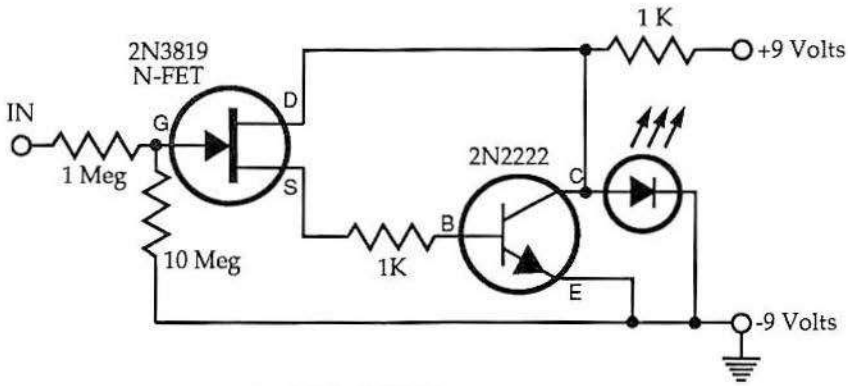


Figure 45 – The FET Electroscope

voltages. In fact, this electroscope will respond to the static build up found in clothes taken from a dryer, or the charge that builds up on a hard rubber comb.

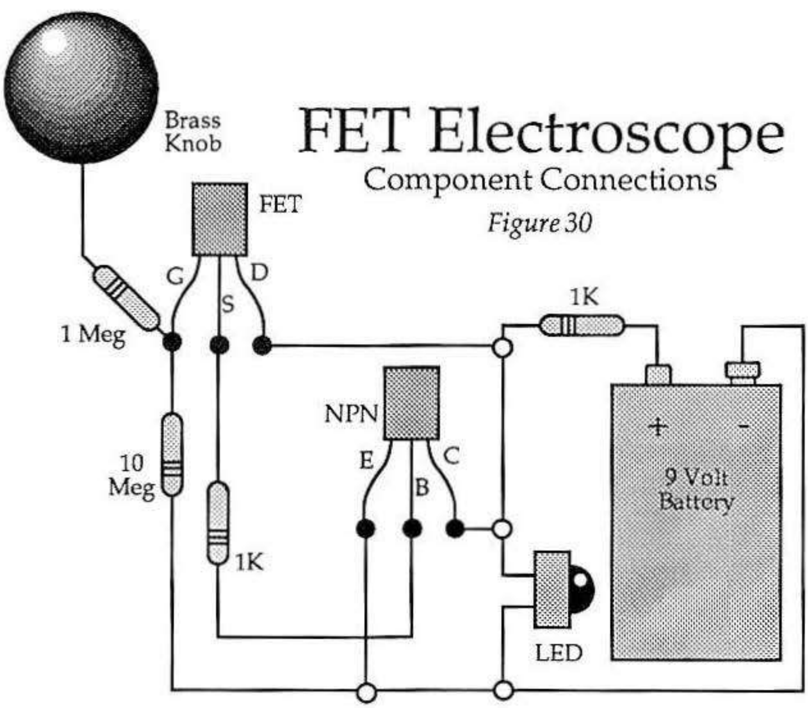
You may want to modify my design. You should consider replacing the 10 megohm resistor with one of a smaller or larger value. It controls the sensitivity of the circuit. The larger the resistor used, the more sensitive the device becomes, the smaller the resistor, the less



FET Electroscope

Schematic Diagram

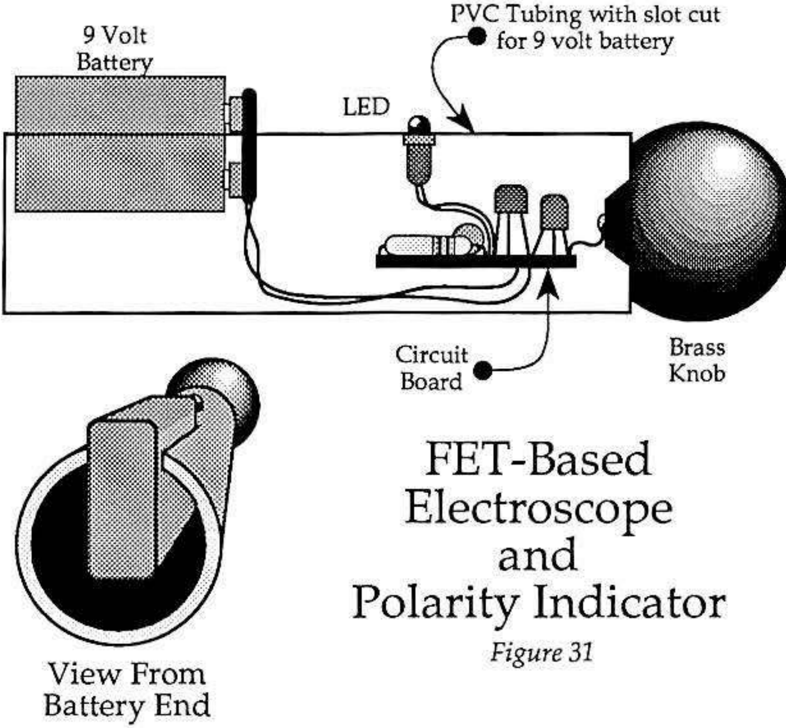
Figure 29



FET Electroscope

Component Connections

Figure 30



FET-Based Electroscope and Polarity Indicator

Figure 31

sensitive – within reason, of course. The resistor can also be removed all together for maximum sensitivity, but the device becomes unreliable because even stray radio emissions will be picked up.

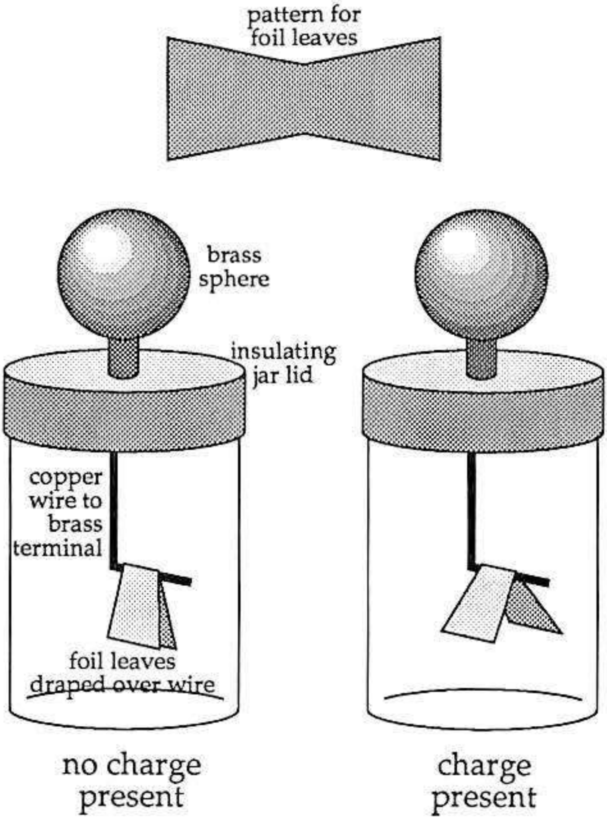
When properly adjusted, the FET scope will light when placed in contact with a positive static charge. Keep in mind that the FET transistor, which is the heart of the circuit, could be damaged by an extremely high voltage, however, I have used my scope without difficulty to more than 30 thousand volts (30 Kv). This voltage was measured by placing the scope directly against the Van de Graaff with an appropriate spark gap.

A MECHANICAL ELECTROSCOPE

A mechanical version of the electroscope can be made quite easily from a glass jar, a little wire, and some aluminum foil. A mechanical electroscope is shown in figure 32.

When the top electrode on this scope is touched to a static voltage source, the aluminum leaves in the jar will separate. This happens because the foil in the jar takes on a uniform charge. Since like charges repel each other, the two leaves of foil are forced apart.

The demonstration of an electroscope can be quite impressive. Although it would be difficult, if not impossible, to calibrate, a



Mechanical Electroscope

Figure 32

mechanical electroscope of this type can also be used to measure voltage. Heavier leaves require greater voltages to separate them. Therefore, the distance the leaves move away from one another indicates a relative voltage.

The Neon Lamp Bank

Another less sensitive but much simpler way to measure low electrostatic voltages is with the use of a neon lamp bank. Figure 33 shows the assembly of such a bank. Ne2 neon lamps are wired in series along a Plexiglas panel as shown in the drawing. Since each lamp fires at about 70 volts, five bulbs wired in series will read a voltage of up to 350 volts. You can quickly see how larger or smaller banks can be easily built. The cost of these bulbs is quite low, so even fairly large banks can be built without great cost.

When connected to a source of high voltage, it is quite easy to see which bulbs are lit. Sometimes, however, you may have to darken the room to get a more accurate reading. Neon lamps are not always easy to see.

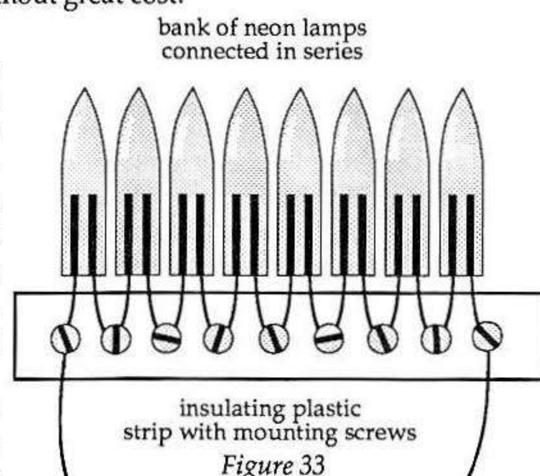


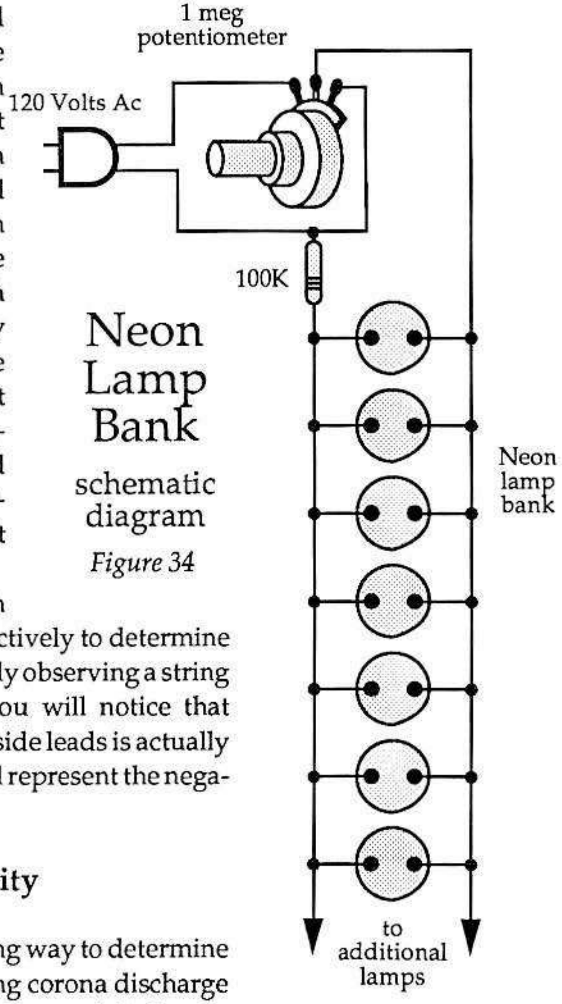
Figure 33

Neon Lamp Bank

You can increase visibility by leaving a small gap between the lamp bank and your high voltage source. Letting a spark periodically jump the gap will trigger the lamp bank. Attaching the bank directly to generator can draw enough current from the generator (load it down) such that it never reaches peak voltage. With a small Van de Graaff a steady stream of bright flashes will occur every two or three seconds.

Though this means of voltage measurement is crude, you could improve it somewhat by using bulbs with very close firing voltages.

The best way to find such bulbs is with the circuit such as shown in figure 34. Note that a volt-ohm meter can also be connected across the leads shown in order to gauge the exact voltage at which the bulbs will fire. By slowly bringing up the input voltage to a set of bulbs wired in parallel you can find which bulbs fire together and at what voltage.



Neon Lamp Bank

schematic diagram

Figure 34

A neon bank can also be used very effectively to determine polarity. After carefully observing a string of flickering bulbs you will notice that only one of the two inside leads is actually lighting. This lead will represent the negative electrode.

Corona and Polarity

Another interesting way to determine polarity is by observing corona discharge from your high voltage potential. Corona discharge is that strange very faint blue glow that surrounds portions of your high potential terminal. To observe it, you will need to be in a darkened room with your eyes fully adjusted to the dark and your generator running.

One might assume that positive corona and negative corona look the same, but this is not true! Positive corona is even and uniform in appearance while negative corona is bushy, often with streaks or streamers that move around.

I first noticed this while using my external Van de Graaff, the same one described earlier. Not having had much experience with this generator, I immediately assumed that the light blue glow I was seeing in the darkness was due to arcing in the D.C. motor. It was too dark to see where the corona was coming from. Fearing the contacts in the motor would eventually be damaged, I tried every method I could think of to stop motor arcing, but the pesky blue glow went on unabated. Finally, I reached out in the darkness thinking I was going to touch the motor, but much to my surprise ended up touching the top of the generator! I had not expected to observe a corona discharge on this machine.

Another interesting fact is that negative corona can be heard! If you find that a hissing sound is coming from your generator, this will be generated by the negative corona discharges!

Using Spark Gaps To Determine Voltage

A spark gap is the best way I know of to accurately measure high voltage without having to resort to very expensive laboratory equipment.

Figure 35 shows the basic configuration of a "sphere gap" capable of accurately measuring up to 90,000 volts. A sphere gap consists simply of two hollow stainless steel spheres 1/2 inches in diameter which are attached to a length of threaded rod with epoxy glue that has

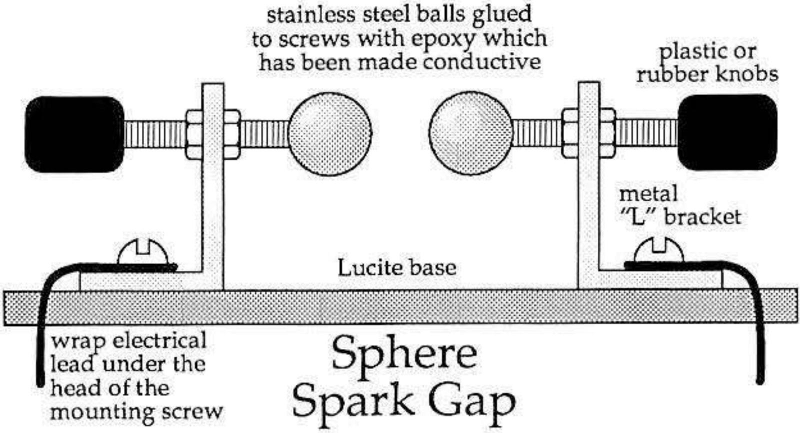


Figure 35

been made conductive by some additive or has been coated with a little silver paint in order to make electrical contact between the sphere and the rod. The rod is threaded through a metal stand, and plastic handles are added to allow the spheres to be turned while the device is operating. The spheres must be at least 3 sphere diameters above the base to prevent distortion of the electrical field which can give inaccurate results.

Another type of gap you can build is a rod gap consisting of two aluminum rods 3/4 inch in diameter. The rods are lined up with each other just like the sphere gap. The ends of the rods are rounded by turning on a lathe. Precision is important. The ends of the finished rods must be as close to hemispherical in shape as possible and must be highly polished. A rod gap of this type will give fairly accurate measurements up to 60,000 volts.

Unfortunately, there are too many variables to give a simple equation for determining at what voltage a spark will bridge a given gap. The only practical solution is to either calibrate your gap by using devices that generate known voltages, or to use a set of measurements which have already been taken.

What follows is a chart of known values for the apparatus described. These charts are excerpts from *Electrostatics* by A.D. Moore.

kV	Rod gap	Sphere gap
5	0.056	
10	0.112	
15	0.170	
20	0.228	0.234
25	0.288	
30	0.355	0.370
35	0.430	
40	0.520	0.531
45	0.625	
50	0.750	0.710
55	0.903	
60	1.122	0.950
70		1.102
80		1.380
90		1.700

Note: Gaps listed are in inches.

One limitation of measuring high voltages with a sphere gap is that you will loose accuracy dramatically if the gap between the spheres becomes larger than the diameter of one sphere. Because of this, you might need a general way to calculate voltages for spheres of different sizes. Also, you may not be able to find a sphere of the exact size mentioned and will need to have a reference for adjusting your figures.

What follows is a listing of spark gaps for spheres of several different sizes. By using these numbers and plotting along a curve, you can remain fairly accurate in determining the characteristics of spheres whose sizes fall between those shown.

Gap Distances in Inches
for a variety of voltages and sphere sizes

	sphere sizes in cm				
kV	2.5	3	4	5	10
10	0.30	0.30	0.30	0.30	0.30
20	0.61	0.61	0.61	0.61	0.61
30	0.95	0.95	0.95	0.95	0.95
40	1.40	1.32	1.30	1.30	1.30
50	2.00	1.82	1.73	1.71	1.65
60	2.81	2.40	2.21	2.16	2.02
70	4.05	3.16	2.80	2.68	2.41
80		4.40	3.50	3.26	2.82
90			4.40	3.93	3.28
100				4.76	3.75

THE "NOON" ION HIGH VOLTAGE METER

OK, I have to admit that it is terribly arrogant for me to name one of my devices after myself, but what the heck. For the record, I won't complain if you affix your name to one of your inventions! I think that you will find this meter which has solved so many of my voltage measuring problems to be an extremely useful tool in experimenting with high voltage.

As we have discussed, the surfaces of a high potential terminal should be smooth and round, ideally spherical, in order to prevent electrons from flying off into space. If we intentionally direct these electrons onto a sharply pointed terminal, the density of electrons will increase to the point where they begin to jump out into the atmosphere that surrounds the terminal. As these electrons stream away, the pointed terminal moves in an opposite direction by virtue of Newton's second law of physics (ie. for every action there is an equal and opposite reaction.)

This reaction is extremely small. However, it is measurable, and can even drive a small motor (described later) or, as I have discovered, push the pointer on a standard panel meter! Since the strength of the reaction is directly related to the voltage accelerating the electrons, it is possible to construct a meter capable of measuring high voltage.

One difficulty with this meter is that, if constructed from off-the-shelf parts, no two meters will read exactly the same due to variations in the exact dimensions of the pointed terminal and the meter itself. It is necessary to use other methods to initially calibrate your meter such as comparing meter readings to voltages ascertained by the spark gap method.

When using your meter remember to keep it well clear of ground or any object that might attract the ions streaming off your high voltage generator. Anything that upsets the stream of electrons can affect the meter reading.

HIGH VOLTAGE AND SAFETY

Because storage devices can accumulate enough electrical charge to be lethal, we must discuss safety.

Most texts simply warn the experimenter to stay away from a high voltage discharge, and, of course, this is a good idea. No shock is completely safe, and people have been injured and even killed by remarkably small voltages.

Even low voltage can deliver high damaging current. A capacitor carrying just a few volts has been known to melt the end of a screwdriver that accidentally bridged its terminals!

If your experiences with electricity are anything like mine, no matter how careful you try to be, electricity will occasionally find

some clever way to zap you when you aren't looking. Because of this, you should know how to determine when any source of high voltage you are experimenting with is safe.

The U.S. Atomic Energy Commission helps us by telling us that a discharge to the human body of 10 joules is known to be hazardous to life. A discharge of a mere 1/4 joules will deliver a heavy shock.

Use the following equation for figuring the charge in Joules:

$$\text{Joules} = \frac{1}{2}CV^2$$

where:

C = Capacitance in Farads
V = Voltage in Volts

What follows (again from A. D. Moore) is a short list of capacitors and the number of kilovolts needed to store up a dangerous 10 joule charge.

microfarads (uF)	kilovolts (kV)
0.002	100
0.20	10
20	1
80	.5
320	.25
2000	.1

From this you'll see that even small capacitors can store lethal amounts of electrical charge. Just because you may be dealing with less than 10 Joules does NOT mean you are safe! Again, remember that no shock is completely safe. If you are careful and use good judgement, you will have little to fear from electricity.

Most of the generators in this book will produce more than enough power to run any of the experiments outlined directly. High voltage static electricity is safe because there is so little current available. A Van de Graaff machine moving 50 square inches of belt per second generates only one microampere. Although the voltage (the pressure behind current) can be very high, there is very little current to be accelerated. Power is the product of voltage times current. One

microampere would have to be accelerated by one million volts to be able to deliver one watt of power. With such low current levels, power levels are necessarily low and relatively safe.

If, however, small currents accelerated by high voltage are stored in a capacitor or bank of capacitors, it is possible to accumulate enough charge at high voltage that when it quickly discharges it can produce deadly levels of current. Some commercial high power static generators go as far as to present the warning "Do not attach capacitors." If you are experimenting with larger capacitors than those described, remember that it is no longer safe to verify static charges by touching terminals! Capacitors can store charges from *minutes to months* depending on the dielectric! Careless or thoughtless use can prove fatal!

Electrostatic generators are unusually safe. Most generators will produce no worse a shock than a good jolt resulting from shuffling across the carpet. However, in coupling your generators to energy storage capacitors you're moving into dangerously high voltages. Be very careful!

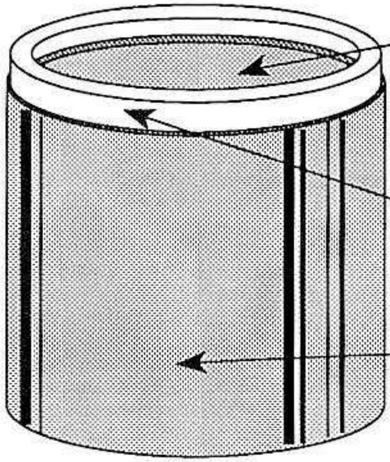
ENERGY STORAGE WITH THE LEYDEN JAR

A Leyden jar is simply a capacitor, that is, a device that stores electrical energy. Like all capacitors it consists of two conducting metal plates separated by an insulator. Figure 36

A brass knob such as those used on the handles of bathroom drawers is attached to an insulator, in this case, a flat piece of Lucite. You could also use cork, plastic, wax, or almost any insulator. The Lucite is cemented to the lid of a jar with a little Silicone glue. A large hole cut in the lid of the jar allows a wire to pass from the bottom of the knob to the bottom of the jar. The inside and outside of the jar are coated with a layer of aluminum foil. The foil should be worked with your fingers until it smoothly conforms to the sides of the jar. A wire is attached to the outside foil, and the entire outside is then wrapped with black tape.

To use the Leyden jar, the wire lead coming from the outside foil is attached to ground. A cold water pipe makes an excellent ground. The brass knob is connected to the output terminal of your generator.

Leyden jars can be assembled in any size, larger jars having larger capacitance. My personal favorite Leyden jar was made from a 5



Leyden Jar & Other Capacitors
showing the
conductor-insulator-conductor layers

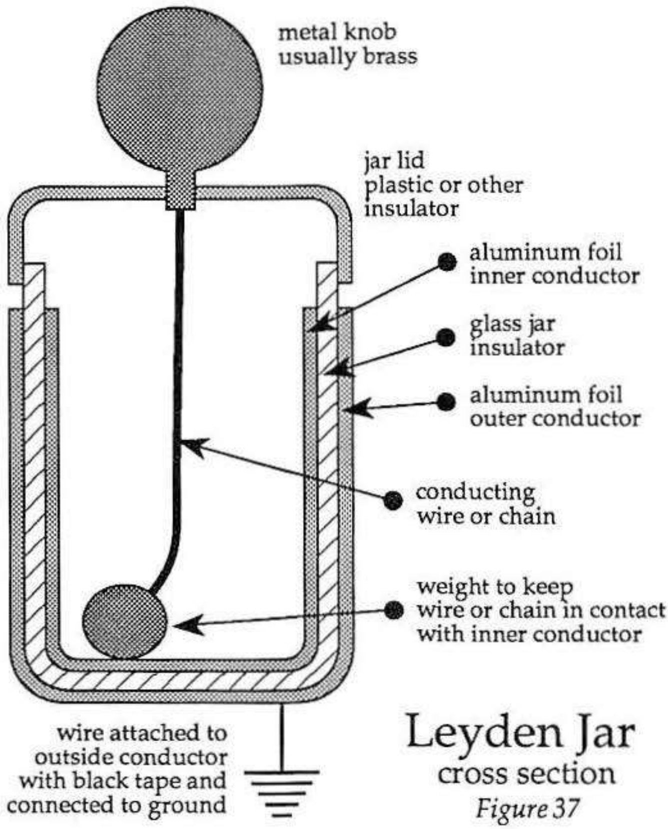
Figure 36

gallon white plastic pail that had contained detergent. This huge capacitor has been charged by the "Classic Van de Graaff" generator. Under good conditions it yields a very heavy, thick, multi-colored, spark of more than 4 inches accompanied by a "crack" that could be heard for some distance.

A word of warning: I made the error of touching this capacitor when I had thought it fully discharged, and though it was partially discharged at the time, I received a remarkably painful shock. This capacitor should be treated with respect. You can never be too careful.

Leyden Jar Tool

One tool you should build for your Leyden jar is a discharge rod. After experimenting with your Leyden jar, you will always want to be sure that it is fully discharged before handling or storing it. This is a very good habit to get into to avoid getting zapped when you are in a forgetful mood.



Leyden Jar
cross section
Figure 37

Electricity often seems to find some way to get into the jar without telling you. I was once shocked by a Leyden jar that was standing a few feet from a generator. It was not until I observed the generator and Leyden jar in a completely darkened room that I noticed a blue glow around a length of wire which had been acting as an aerial above the Leyden jar and had partially charged it although it was not even directly connected to the generator!

To make a discharge rod, simply take a length of heavy copper wire and bend it in a "U" shape. This "U" should cover the distance between the brass ball and the aluminum side of your Leyden jar. Attach an insulating handle to the center of the "U". Make sure this handle is long enough that a spark won't find its way along the handle

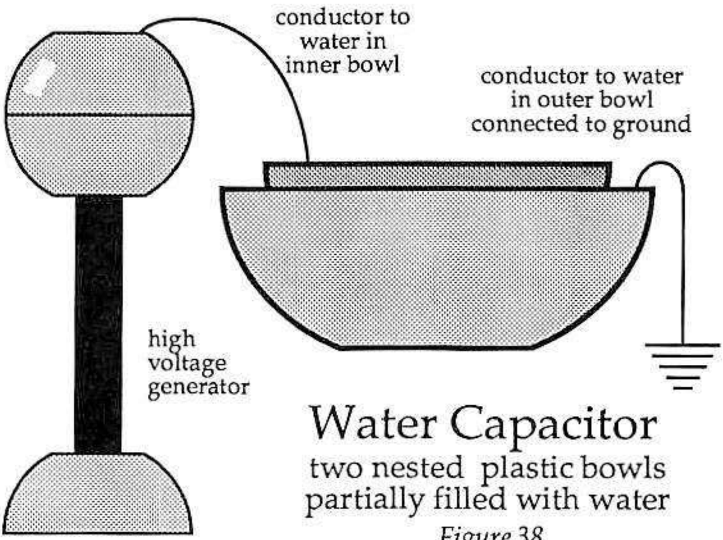
to your hand. Holding it by the plastic handle, you can bridge the gap between the brass ball and side of the Leyden jar, and safely discharge it.

Discharging a large Leyden jar with this tool can be lots of fun since a large noisy spark can be safely produced. This provides a terrific demonstration for those who doubt the power of static electricity!

THE WATER CAPACITOR

Believe it or not, ordinary water and plastic bowls can be used to form an extraordinarily high dielectric, and make a good capacitor. Figure 38. A water capacitor is nothing more than two plastic bowls set inside one another each being partially filled with tap water. Any tap water will be somewhat conductive like the metal plates of the Leyden jar because of impurities. Dissolved salts in the water form positive and negative ions which move readily. The plastic wall of the inside bowl forms the dielectric while the water in each bowl forms the electrodes. A small capacitor of this type having 53 inches of useful surface area has a capacitance of approximately 100 pF.

This type of capacitor was supposed to have been a favorite of inventor, Nikola Tesla. Tesla, it is said, would wire together banks of



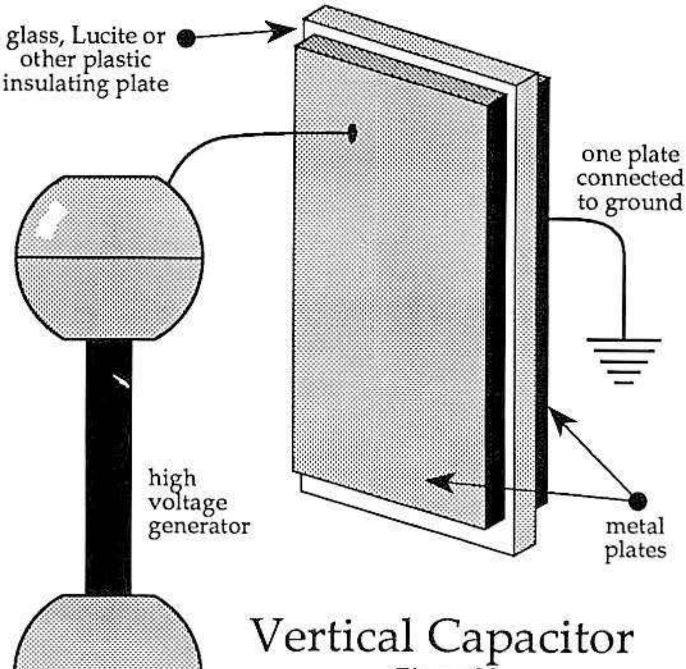
Water Capacitor
two nested plastic bowls partially filled with water
Figure 38

insulated metal trays which were filled partially with water. By connecting these water capacitors in parallel, Tesla could reach very large storage potentials with a minimum of effort.

Plate Capacitors

As you have undoubtedly gathered, all that is required for a simple capacitor to hold a charge are two conductive plates with an insulator (dielectric) in between. There are an infinite number of configurations to be experimented with. Figure 39 shows what is probably the simplest useful capacitor possible.

The largest plate capacitor I attempted during the writing of this text was one made from aluminum foil and my sliding glass door. As soon as I became interested in electrostatics, and making high voltage capacitors, I started seeing the makings of capacitors everywhere. Every day I looked at my sliding glass door, and every day it looked less like a door and more like a capacitor. Finally I broke down and



Vertical Capacitor
Figure 39

bought a large roll of aluminum foil and some tape. After a thorough cleaning, I transformed my door into a giant capacitor, by taping sheets of foil to each side of the glass. But alas! The results were disappointing. Temperature differences between the inside and outside of the glass caused condensation and all the problems that moisture brings, and the large sharp edges of the foil which I attempted to insulate bled off charge rapidly into the air. The foil did odd things such as crinkling and making sounds when charged, but failed to yield an interesting spark or hold a charge for any length of time at all.

I'm sure you'll come up with as many ideas as I do. Most recently, a television special showed the huge metal domes on buildings in Moscow square giving me visions of tremendous high potentials. As I watched, the buildings kept looking more and more like high potential tops of Van de Graaff generators and less and less like buildings. I think this high voltage stuff is affecting my mind! I think it's a good thing that I don't live in Moscow.

Calculating Capacitance

Once you begin designing and building capacitors, you will undoubtedly want to know what charges they are capable of storing. Capacitance is fairly easy to calculate, although homemade capacitors will be much less than perfect and probably perform more poorly than calculations might indicate. The following equations will give you a good idea of what can be expected from your designs.

Air is a good dielectric, and is accounted for in calculations. If we have two metal plates standing parallel to one another with air between, the equation for finding capacitance in picofarad is:

$$C = .08854 \frac{A}{S}$$

Where

A is the area of one side of one plate in square centimeters

S is the distance between plates in centimeters.

The same equation can also be revised for inches:

$$C = .2249 \frac{A}{S}$$

Note that these equations remain fairly accurate as long as the smallest dimension of the plate is ten or more times "S". In other words, the area of the plate should be much, much larger than the distance between them.

Different materials have different insulating capabilities which are reflected in their dielectric constant. Since you will want to use materials other than air as a dielectric, you will need to look up the dielectric constant from standard tables. You'll find that Plexiglas provides about four times the dielectric strength of air. A capacitor built from two conducting plates would have four times the capacitance of an air capacitor.

Another example: We might calculate from the equation above that a capacitor with a desired plate size has a capacitance of 100 pF using air as the dielectric. Using the chart below we see that if dry paper were substituted for air, the capacitance will be raised to 200 pF.

Shown below are some typical dielectrics relative to air borrowed from Attwood's book *Electric and Magnetic Fields:*

Dielectric Constant	Material
1	Air
25	Ethyl alcohol
2.5	Transformer oil
4.5 - 7	Various types of glass
6.8-8.4	Plate Glass
8.0	Window Glass
4.1-6.1	Pyrex
5.4-5.8	Bakelite
2	Dry paper
2.3	Paraffin
4	Plexiglas
2.5	Pure rubber
4	Wood

Capacitors can be connected in parallel or in series. Parallel connection increases total capacity. The total capacity is the sum of the individual capacities.

$$C_{Total} = C_1 + C_2 + C_3 + \dots$$

For example, three capacitors having capacity of 10, 20 and 30 pF each would act as one capacitor having 60 pF when connected in parallel. The breakdown voltage of the combined capacitors is only as great as the lowest breakdown voltage of any single capacitor.

Calculating the capacitance of capacitors connected in series is more complicated, being the reciprocal of the sum of the reciprocals of the individual capacitances.

In series you would figure:

$$C_{Total} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots}$$

For example, three capacitors have capacitance of of 2, 4 and 4 pF. When connected in series, the total capacitance would be 1 pF. Although capacitance has decreased, the maximum working voltage has increased. If each capacitor had a maximum working voltage of 10,000 volts, the series connection would have a maximum working limit of 30,000 volts.

Power Capacitors

You can build a very powerful capacitor by creating a stack of alternating sheets of dielectric material and metal plates. On a large sheet of dielectric place a metal plate, then another sheet of dielectric, another metal plate and so on. The plates must be absolutely clean and free of even the tiniest contaminant or the capacitor will not work. To complete the capacitor connect alternating metal plates to one lead and the remaining metal plates to another.

For your first attempt, build a power capacitor with 5 sheets of dielectric and 3 metal plates. Connect the top and bottom metal plate to one lead, and the middle metal plate to another lead.

Benjamin Franklin — The Turkey Killer

Benjamin Franklin, an incurable prankster, was an ardent experimenter with electrostatic machines. Amazing as it may seem, according to his biography, the major reason Ben Franklin tried his dangerous kite experiment was that he was tired of charging his Leyden jar by hand cranking his static electricity generator. He wanted to charge it with lightning which he was able to do without getting himself killed! (Note: this method of charging a Leyden jar is not recommended for those other than "founding fathers" and other experimenters who seem to have a supernatural gift for avoiding harm. In other words, don't you try it.)

Franklin's hand-cranked static machine was large enough when coupled to Leyden jars to produce a lethal voltage. In fact, Franklin often used his static machine to kill his Thanksgiving turkey. In his own words *"... to the amazement of many... A turkey is to be killed for our dinner by electrical shock, and roasted by the electric jack, before a fire kindled by the electric bottle..."*

Franklin's pranks were not without risk. Just a short time before his famous kite experiment Franklin accidentally took the full force of his turkey killing device. He wrote, *"Being about to kill a turkey by the shock from two large glass jars, containing as much electrified fire as forty common phials, I inadvertently took the whole through my own arms and body, by receiving the fire from the united top wires with one hand while the other held a chain connected with the outside of both jars. The company present (whose talking to me, and to one another, I suppose occasioned my inattention to what I was about) say that the flash was very great and the crack as loud as a pistol; yet, my senses being instantly gone, I neither saw the one nor heard the other; nor did I feel the stroke of my hand.... I then felt what I know not well how to describe: a universal blow throughout my body from head to foot, which seemed within as well as without; after which the first thing I took notice of was a violent quick shaking of my body, which gradually remitting, my sense gradually returned.... That part of my hand and fingers that held the chain was left white, as though the blood had been driven out, and remained so eight to ten minutes after, feeling like dead flesh; and I had a numbness in my arms and the back of my neck that continued till the next morning..."*

Franklin's account of his own mishap should certainly give thought to those who do not take the dangers of static electricity seriously!

ELECTROSTATIC EXPERIMENTS

The experiments here are divided into two categories. The first group describes electrostatic experiments that can be performed for an audience. In other words they're merely for entertainment.

The second section features experiments which possible useful applications of electrostatics which are not often discussed. Many of these "useful" experiments could be or are being developed into very real, marketable industries and should be particularly interesting to the serious experimenter.

Hair Raising Experiences

Using electrostatic voltages to make a person's hair stand on end is a classic experiment every audience should see. It can be done in a number of ways. Find a subject with hair that is light and clean. With some experience you will be able to recognize the best subjects immediately. Next, convince the subject that the ominous apparatus that they have just seen throwing four inch sparks will not harm them.

You may want to explain why the experiment is perfectly safe by describing the "skin effect" of high voltages. This effect refers to the strange fact that voltages of this order travel only on the outside or "skin" of the object they pass over and will not travel through the inside of a body where they could do any harm. For alternating currents this is a true skin effect, but for direct currents there is a similar effect that occurs probably because of the repulsion of like charges rather than due to a true skin effect.

The subject should stand within reach of the generator and should be well insulated from any ground. This is accomplished by having the subject stand on a large insulator such as an overturned plastic bucket, or, as a joke, a stack of college text books since they are usually very dry. Instruct the subject to place one hand on the high potential terminal, and then turn the generator on. Remember to remind a nervous subject not to remove his hand from the terminal until the experiment is completed since removing his hand could provide a

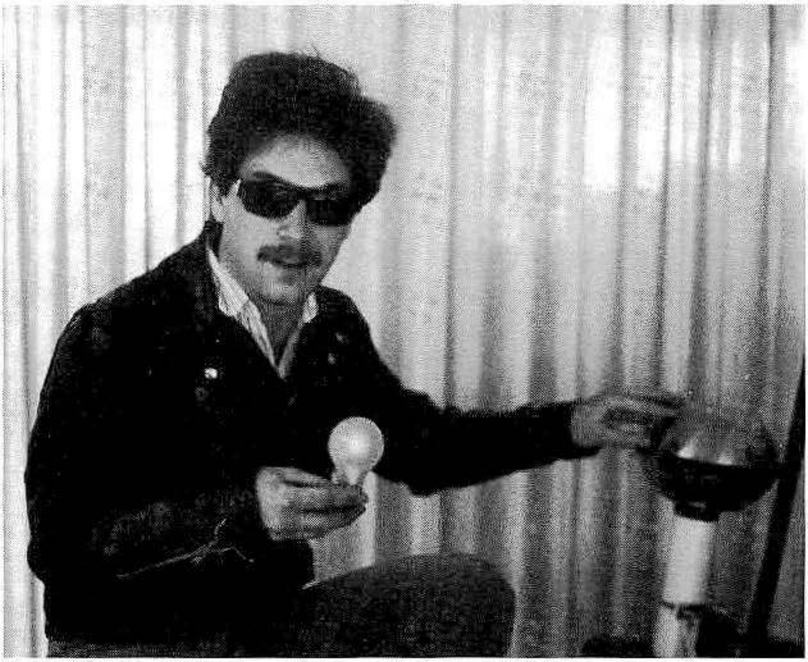


Figure 40 – The author's hair is usually flat and combed somewhat back. After a few minutes connected to a running Van de Graaff generator, and he's ready for a punk-rock concert!

shock. Depending on the output of your generator you may need to allow it to run for several minutes before your subjects hair will begin to rise. Having your subject shake his head occasionally with speed up the process.

During this whole procedure the subject will not feel the electricity passing over him other than perhaps a light tickling as his hairs stand on end. What is happening is that the subject's hair and whole body is taking on a charge from the generator. Since all of the hairs have the same charge whether it be positive or negative, and because like charges repel each other, every hair is repelled from every other hair and any nearby parts of the body. Warnings: **1) Don't use capacitors. 2) Hairspray is flammable. 3) Voltages over 500,000 are unsafe.**

Strangely enough, your generator will actually have a higher potential with someone is touching it than when it is operated alone

since it can now use the person's body as a high potential collector. The success of this experiment depends largely on the subject's hair. Some women with short frizzy hair will have their hair stand out nearly straight from their head!

After the experiment is complete, have your subject remain standing on the insulator. This will allow the charge accumulated in their body to bleed off and will reduce the possibility of a large spark occurring when they eventually touch something that is grounded.

There are a few simpler although perhaps less dramatic ways to perform the same experiment. One is to make a wig out of fuzzy yarn and to place it over the generator's high potential terminal. You can place it on the spherical terminal of a Van de Graaff generator to simulate a person's head. Some Mr. Wizard impersonators even like to put a pair of plastic sun glasses under the wig to give the generator a little character. After the generator has run for a time, the hairs of the wig will stand on end.

A very quick way to demonstrate this effect is to simply take a few hairs from an old hair brush and place them on the generator's surface. They will immediately stand on end, and will often fly off the generator all together! Many different light weight materials can be used for these type of experiments. Bits of styrofoam work extraordinarily well.

The Magic Wand

As discussed, smooth, round objects tend to hold their charges while sharp pointed objects will allow electrons to fly off in a stream sometimes referred to as an "electric wind." The effects of this wind can easily be seen. Connect a short length of wire to your high potential terminal and hold the free end of the wire with a handle made of an insulating materials such as plastic. Point the end of the wire toward a lighted candle, and observe the flame. The flame will bend mysteriously away from the invisible "electric wind." In a well darkened room with ones eyes well adjusted the "wind" may actually be visible.

Another interesting experiment is to use the wand to chase a soap bubble. Because there are two forces acting on the bubble, the outcome of the experiment may be unpredictable. One force is the charge of the generator itself which draws the bubble toward the wand. The other

force is the electric wind from the wand that pushes the bubble away. How the bubble will act is anyone's guess! It depends on which force is dominant.

A little later on we'll use this surprisingly powerful wind to create a small pinwheel motor.

Levitation

There are a number of ways that you can levitate lightweight materials using your generator. The easiest ways to demonstrate this is to simply spread very small shavings of styrofoam along the top of your generator. When the power is on, the pieces will take on the same charge as the surface of your generator and be repelled by it since like charges repel one another. The bits of styrofoam will levitate off into the air after the generator has been on a few seconds.

An entertaining experiment can be done by placing a number of tiny styrofoam balls in a short section of clear glass or plastic tubing about 2 1/2 inches in diameter and a few inches in length setting on your high potential terminal. Cover the top of the tubing with a metal plate, and connect it to ground. When your generator is turned on, the balls become charged and levitate to the top of the plastic tube. When they touch the metal plate at the top of the tube they lose their charge to ground and fall back to the generator again. The balls will oscillate between the ends of the tube until the generator is shut off. You should coat these balls with a conductive paint for a more complete charge transfer.

If you enjoy reproducing electrostatic experiments as they were originally done, you might want to try making your own old-fashioned pith balls instead of using styrofoam. Pith balls were used for these experiment before modern products like styrofoam were available. Pith balls are made by removing, shaping, and drying the insides of certain plants such as dandelions. Details can be found in old physics textbooks before 1900. I'll stick with good old styrofoam.

Place larger bits of styrofoam on your generator, and turn your generator on while touching the bits with your hand. The styrofoam will assume that you are ground and that your generator is a high voltage source. One side of the styrofoam will be charged one way, and the other side of the styrofoam the other. After removing your

hand, a number of things can happen. The styrofoam may flip over and be stuck to your generator like a magnet. The styrofoam may stick to your hand like a magnet. Or you may find the styrofoam floating on end as the hair did in the last experiment.

An interesting trick can be performed by passing your hand over the styrofoam remaining on your generator terminal. As you do so, the electrical charges in the foam and in your hand will cause the styrofoam to jump about.

I have meant for some time to place a metal plate on a table underneath a table cloth and to energize that plate from a hidden electrostatic machine. I could then sit at the table and "mysteriously" move light weight objects such as bits of hair, sawdust, styrofoam or other similar materials around the table simply by passing my hands over them. I think this would make a very convincing illusion of mental telekinesis. Try it.

Lighting Without Wires

If you or your friends doubt the power of your generator, have on hand a supply of Ne2 neon bulbs which are available for less than a dollar at any electronics store. Remind those onlooking that it takes at least 70 volts to light a neon bulb. Hold one lead of the neon bulb in your hand and move the bulb toward your generator. Within inches, or even feet, the bulb will flicker or light. I have seen some experimenters hold the bulb in their mouth while reaching toward a generator with their hand. Seeing a 70 volt bulb light in a persons mouth with no wires attached is an impressive demonstration.

You may want to try large florescent bulbs as well. When my generator has been running I have seen flickers in the florescent lights in the ceiling of my home. These bulbs are many feet above the top of my generator yet respond well in a darkened room.

Perpetual Motion

Anything that people assume can't be done interests me. Many of the greatest inventions of all time would never have come into being if their inventors hadn't at one point been told that it couldn't be done. Currently, perpetual motion qualifies as such.

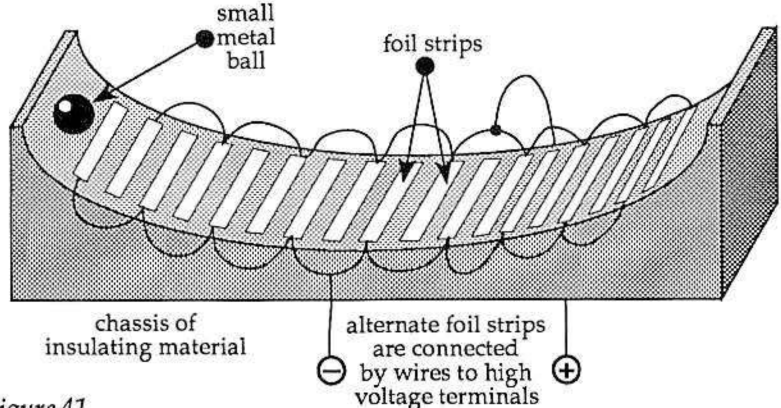


Figure 41

"Perpetual Motion"

The following device doesn't really qualify as perpetual motion, but it appears to be! Figure Pl shows the device. The idea is simple. A few light-weight conductive balls are released onto a U-shaped track on which the balls rock back and forth. It is normal to assume that the balls will slowly lose their energy and come to a stop in the center of the track. Instead, because of the electrodes in the track,the balls continue back and forth indefinitely and even pick up some speed along the way.

What has happened is that you have constructed simple electrostatic motor. As the balls pass over the foil strips they pick up the charge from that strip. Having the same charge as the strip, they are repelled by that strip and are simultaneously attracted to the next strip which has a dissimilar charge. Inertia will cause the balls to roll over the dissimilarly charged strip and on to the next. The electrostatic forces replace the energy lost in rolling friction. In this manner the balls will remain in motion for as long as power is supplied.

If you wish to really complete the illusion given by this device you will naturally want to hide the foil strips from view. To do this you could either use a conductive material other than foil that blends into the background, or, if your generator is powerful enough, you could probably bury the foil strips under the ramp material and still transfer a sufficient charge.

Trick Gun

We know that like charges repel one another. This has been demonstrated with the 'hair' experiments and others. What would happen if we introduced a charge into a liquid, and then shot that liquid out in a stream? We can find out with the use of a squirt gun. Purchase an inexpensive water gun that stores its water in the handle. Drill a small hole into the handle and twist a brass sheet metal screw into the hole. You may want to put a little Silicone glue around the top of the screw to make sure that this point will not leak when the gun is later filled with water. The brass screw provides electrical contact between your hand and the water.

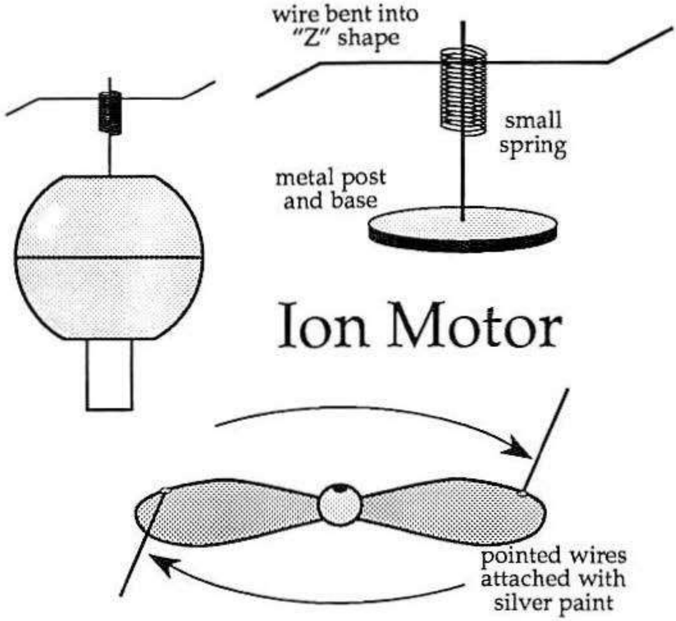
Fill the gun with water, and pump out a few squirts. The water will come out in its customary straight stream probably covering the length of the room. Then stand on an insulator and charge yourself up as described earlier. When you squeeze the trigger, a stream of scattered droplets will be ejected only a few feet. What has happened is that all water droplets have a similar charge so each droplet is repelled by every other droplet. Other than being just an interesting way to get an unsuspecting friend wet, this mechanism can be applied anywhere that a liquid must be atomized.

I've wondered about making an electrostatic chamber on the carburetor of my car to see if better atomization of the fuel would result in better combustion. But first I need to check into the dangers of a spark occurring! I don't really want to blow myself up!

An Ion Motor

There are several different electrostatic motors that can be run by your generator, the simplest being an ion motor. You can make one by simply bending a length of light weight wire into a "Z". At the center of the "Z" shape, place a conductive bearing. Nothing fancy is required. In fact, just looping the center of the Z around an axle may work. Make sure however, that the Z will rotate very easily. A simple schematic of the ion motor can be seen in figure 42.

When power is applied to ion motor electrons stream off the pointed ends of the wire creating an electric wind. The force of the wind pushes the wire in the opposite direction. Again, for every action



Plastic Toy Airplane Propellor
Figure 42

there is an equal and opposite reaction. If your rotor is well balanced and the bearing friction is very low, your motor can and will achieve speeds of several thousands revolutions per minute! Of course, the torque generated by this motor will be very, very small. Nevertheless, it is fascinating to watch a motor propelled by a stream of electrons!

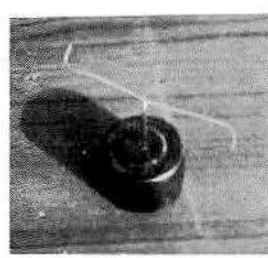


Figure 43 –Simple Ion Motor

Although the thrust of this motor is very small, I am certainly not the type of experimenter to let this hard-earned stream of electrons get away without doing some useful work along the way. I have attached one of my pinwheel motors to a tiny plastic airplane propeller as shown to blow a little air cool air my way. I think this is probably one of the few fans that I know of that must be connected to 100,000 volts or so to operate!

Another thought that I had for this fan was to drive it with a negative charge. Negative ions are thought to have many health benefits, and to cut down on pollutants in the air. Negative ions apparently attach themselves to specks of airborne dust and cause them to fall from the air. There are a number of negative ion generators being marketed for this purpose. I thought that a spinning propeller of this sort would be an absolutely outstanding way of both distributing and producing negative electrons in a room environment.

Ion motors also have serious applications in space travel. The Soviets have used ion motors to propel some of their long range probes. The problem with these motors is that the thrust is very small. However, ion motors offer at least two enormous advantages. First, they can be powered by a nuclear or solar electrical source which can provide power far longer than conventional chemical rockets. Second, an ion motor can provide higher velocity thrust than current chemical rockets because the nozzle velocity of a rocket is limited by the internal pressures that can be safely generated inside the rocket motor. An efficient ion motor can accelerate ions to speeds approaching the speed of light! Although the thrust is small, over time the space craft could itself approach the speed of light, at least, in theory.

A few tips for getting the best operation out of your ion motor—Make sure that your rotor is well balanced especially if you want your motor to be self-starting. Your rotor should spin easily for several seconds when tapped lightly by your finger. The more freely your rotor can spin, the faster it will revolve. The bearing used in a radiometer would make an excellent ion motor bearing.

Run your generator/motor in an area free of objects that might provide sources of ground. My first ion motor was well built and carefully balanced, yet it refused to spin. When I reached down to give it a tap to get it started, it refused to move. In fact it felt as though it were being held in place by a magnet. It was then that I realized that one of the arms of the rotor must have been attracted to an object with an opposite charge. That object turned out to be me! When I moved a short distance away, the ion motor sprang to life and immediately whirled up to several hundred RPM.

For this motor, voltage is more important than current. The motor will run and do useful work on currents under a microampere. Electrostatic motors have been run with currents of less than .001

microamperes, and have even from the earth's electrical charge itself.

Another interesting use that I have found for an ion motor is that of a primitive high voltage meter. The higher the voltage, the greater the thrust from the motor. This may be used to move a pointer such as in a panel meter or may be used simply to a relative indication of voltage.

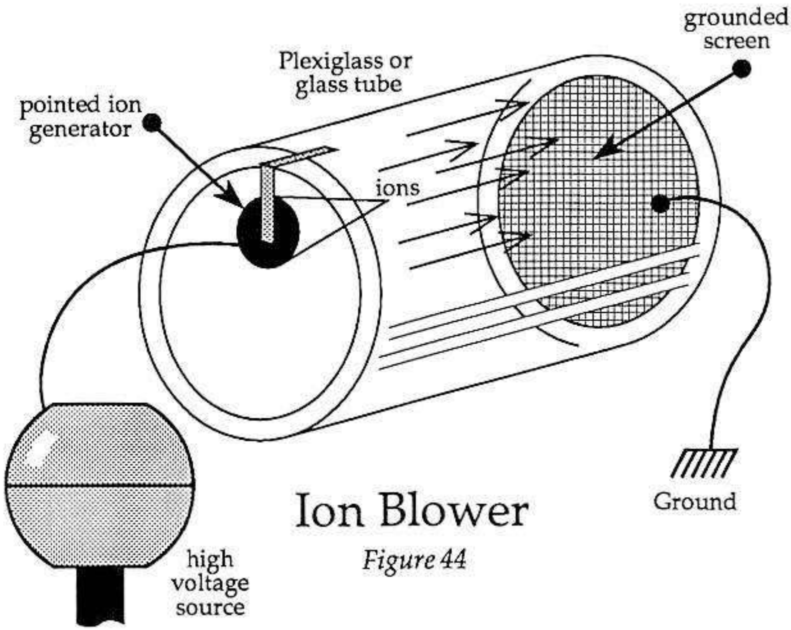
I like to place a small ion motor on top of my Van de Graaff generator when I am charging capacitors. When the capacitors are charging, the motor will not move since the charge is being bled off from the generator to the capacitors. When the capacitors are fully charged, they stop drawing current from the generator. The terminal voltage rises, and the motor begins to spin. This is a very useful application of the ion motor since it is usually impossible to tell when a capacitor is fully charged any other way.

I am told that ion motors have been used in scientific toys such as those that can influence a balsa airplane in flight. Gustave LeBon's electrified rocket was a small aluminum foil rocket that could actually fly on electrostatic forces (Patent No. 2,018,585). I have not seen these devices, but they sound like something worth investigating.
Experimenting with "micro" sources of power can bring out the engineer in everyone.

An Ion Blower

The last experiment uses a stream of ions to propel a small rotor. Since in essence what we really have is a little jet engine, why not put our blower into a tube and see if we can pull a little air along with it. Figure 44 shows one possible configuration.

One end of a small, clear tube such of glass, Plexiglas, or other insulating material is fitted with a sharp metal point. A metal screen covers the other end. Electrons reach a high density at the metal point, break free into the air, and stream through the tube to the screen at the far end. As they move rapidly through the tube, they pull some of the air inside the tube with them. Obviously, a blower of this type has very low efficiency probably in the neighborhood of 1% under ideal conditions, Nevertheless, a puff of smoke at the intake side of the tube will easily be drawn through.



Ion Blower

Figure 44

Clearing The Air

Before moving on, here's another interesting smoke experiment you can try. Get a clear plastic or glass jar having no metal parts. Drive a pointed nail through the center of the lid. Blow a little smoke into the jar, and seal the jar with the lid. Next, connect the head of the nail to the output terminal of one of your high voltage generators.

As charge is applied to the smoke, it will begin to swirl. Soon the smoke will seem to disappear, although in reality it has been redistributed along the sides of the jar.

Variations of this effect are used in industry to place very fine films on surfaces. Similar electrostatic methods are being used to make sandpaper. When the tiny metallic abrasive particle are distributed along the surface of the sand paper they are given a charge that causes them to stand on end creating sandpaper with a better abrasive action.

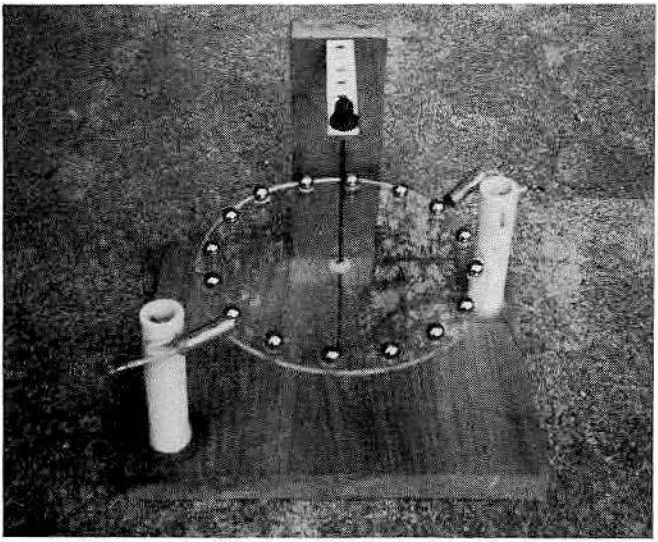


Figure 45 - Franklin Motor – Using large sling-shot balls and a simple Lucite disk, this little motor quickly speeds to over 600 rpm on less than 1 microampere of current!

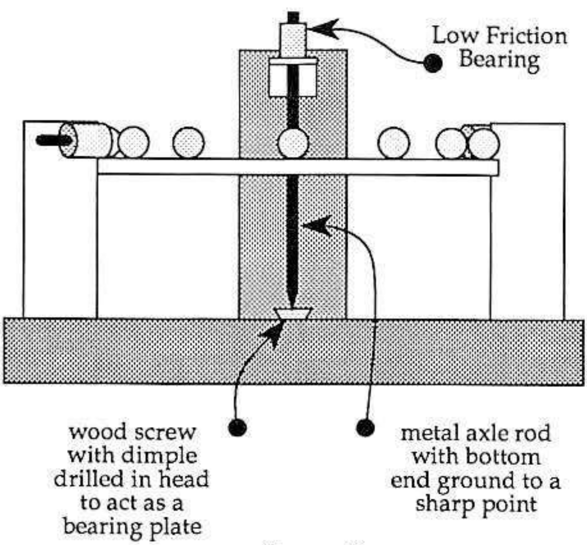
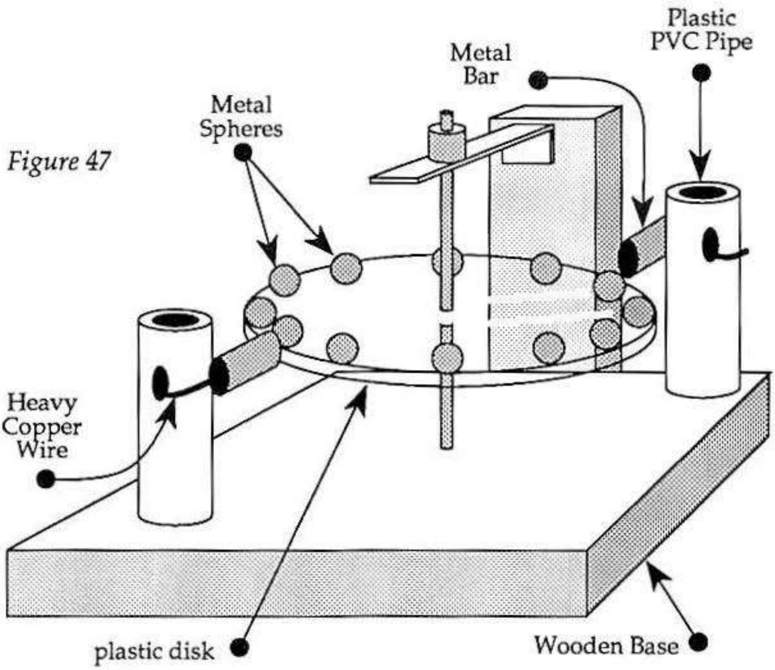


Figure 46

Franklin Motor

Front View

Figure 47



Franklin Motor

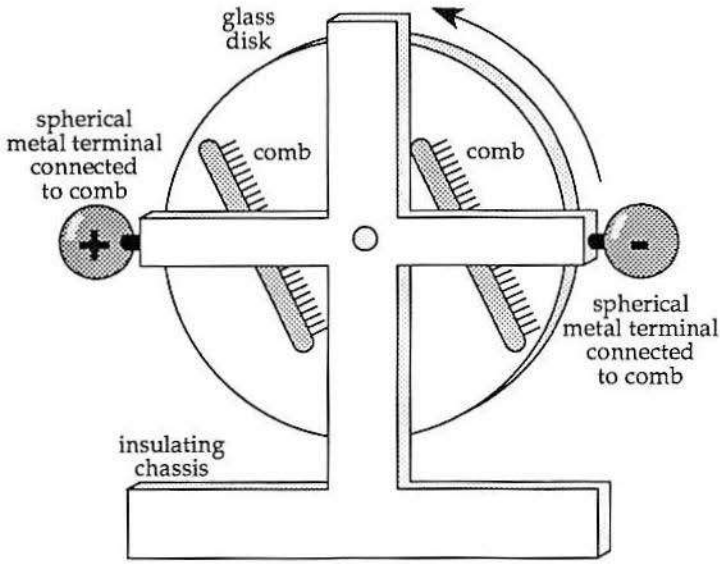
THE FRANKLIN ELECTROSTATIC MOTOR

The Franklin motor, named after its inventor Benjamin Franklin, is often said to be the first electric motor ever made. Its construction is simple, and, in fact, it is very similar in operation to the Dirod generator described earlier which can be run as a motor although inefficiently. Figure 47 shows the basic Franklin motor.

A series of lightweight spheres is glued in place along the outside of an insulating disk of Plexiglas, glass, etc. As these spheres rotate, they pass through the corona emanating from a highly charged high potential terminal at each side of the disk. One terminal is charged negatively and the other positively. As a sphere passes a terminal, it picks up a charge that will be attracted to other terminal causing the whole assembly to turn until the high voltage is removed.

One modification that you might like to experiment with is to

make the Franklin motor self-starting. This can be accomplished by adding points on the high potential sources to create an electric wind that gives the spheres just enough of a nudge to start the rotor revolving.



Corona Motor
schematic diagram
Figure 48

Poggendorff's Corona Motor

Franklin's motor works by charging a series of spheres as they pass by alternating high potentials. It is also possible to alternately charge an insulating surface as it passes near high potential terminals. Plexiglas, glass, and probably other materials will work. A drawing of Poggendorff's motor is shown in figure 48.

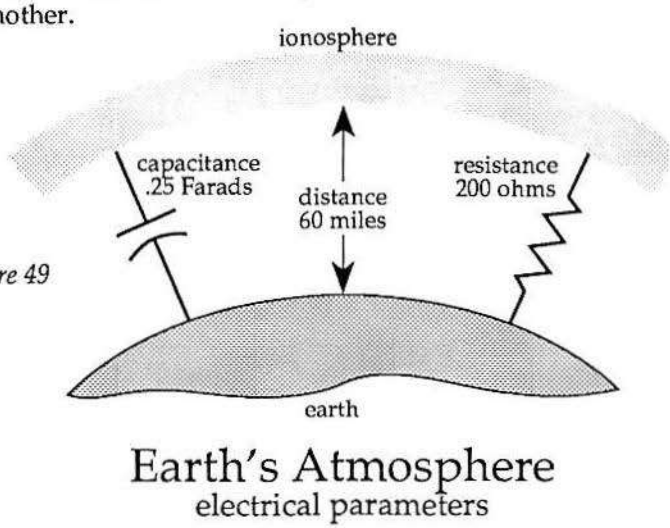
Here is how it works. Notice that there are two sets of brushes or combs with sharply pointed ends mounted at an angle. One brush sprays a negative charge onto the disk and the other a positive charge. As the disk continues to revolve, the charges on its surface find themselves attracted to the entire oppositely charged comb – not just

the tiny spray points. It is important that the brushes be mounted at an angle, so that charges on the disk may be attracted to the comb of opposite polarity before they are replaced with an opposite charge as the disk rotates under the points of the comb. Understanding how a motor like this works is simple. Getting one balanced well enough to be self-starting and smoothly running takes quite a bit of patience. It is nonetheless an exciting and interesting project.

Atmospheric Electricity

The earth itself is a huge electrostatic generator. In the air at any time there are some 200 volts of electricity encircling you all of the time. The reason that we aren't being zapped all the time is simply that we are all at roughly the same potential. That is we all have the same level of charge, so, the electricity has no reason to move from one point to another.

Figure 49



Between the earth and the electrically conductive ionosphere, both of which store electrical charge, exists an electrical potential. The same sort of buildup exists between clouds and the earth. When the potential builds to a level great enough, the air ionizes, loses its insulating capacity and becomes an excellent conductor. The result is a huge arc of static electricity we call lightning. As current flows between the cloud and the earth, the potential is reduced until the arc

can no longer be sustained, and the lightning bolt is extinguished. It fascinates me to think that I live on one of two highly charged electrodes.

As an electrostatic generator the earth is fairly impressive. Between two and six thousand thunderstorms are in progress at any one time. Worldwide, a hundred bolts of lightning strike the earth every second. It is estimated that this gives the earth a high voltage potential of approximately 360,000 volts between ground and ionosphere with an average lightning bolt conducting 1800 amperes. The density of the electric field decreases as altitude increases. Near the earth's surface, however, the field is estimated to be approximately 100 volts per yard of height.

I say that the earth is fairly impressive because for all its size it is limited to these voltages by the fact that the atmosphere is relatively conductive having a resistance of approximately 200 Ohms. This is a relatively low resistance which quickly bleeds away charges.

Although it can take a significant amount of time depending on weather conditions, any conductive material insulated from ground can acquire charge from the surrounding air, and become charged to a high potential. Although the charge accumulated is usually negative in polarity, thunderstorms and other atmospheric conditions may create a positive potential with respect to ground. Radio antennas and flag poles insulated from ground have been known to throw hefty sparks and even start fires.

Plugging In To The Earth's Charge

If you're as curious as I am, you're asking yourself, "Can I tap into this charge?" The answer is yes! The first order of business is to measure and verify that a charge is present. If you are a skeptic like me, you've "gotta see that needle move" before you are going to believe there is something there!

The best antenna for capturing atmospheric charge is a metal structure, insulated from ground, pointing straight up into the air. The simplest, and probably easiest way to accomplish this is to simply attach a length of very light, bare, copper wire to a large helium balloon. This can be dangerous! Remember to avoid power lines and airports if you plan to launch such an energy-gathering balloon!

Having your bare copper wire come in contact with a high-tension power line is not a pleasant way to die! Thunderstorms are extremely dangerous. (Ben Franklin was lucky to have survived his experiment.)

The bottom of the wire should be attached to a high quality insulator well above ground. Attach one lead of a extremely sensitive meter to ground. Occasionally attach the other lead to the vertical metal conductor. Be careful! Do not take for granted that the potential will be harmless! If left unchecked it could easily reach a level that will bite you. You may find that it can take an hour or more to build up a significant charge, however.

At one time I tried using a kite flown with bare copper wire but had mixed results. I experienced significant difficulty with the wire kinking as I let it out and reeled it in, in response to changing winds.

Another time I hooked a diode into the line and got surprising voltages, but I had been fooled. The diode and coil in the meter had made a primitive crystal radio. I was extracting power from the atmosphere that had been placed there by radio broadcasting stations. Although this is not static electricity, it is nonetheless interesting because it is a demonstration of wireless transmission of power that Tesla was trying to perfect.

An antenna of this type has been used quite adequately to run a corona motor from the natural potential that exists between the earth and its atmosphere! A motor of this type must be extremely well built having great sensitivity and very low friction bearings. I have seen such a motor run, but I have not run one of my motors from this charge.

Because of weather, it can take a long time to build the potential up to a level capable of doing useful work such as moving a sensitive meter or a small corona motor. Several methods have been devised to speed up the charging process. Early experiments devised by Lord Kelvin used an insulated metal tank filled with water suspended above the ground constructed in such a way so as to allow a steady stream of water droplets to reach the ground. Appropriately, he called the setup a "water dropper." He reasoned that the surface of each water drop would be an extension of the surface of the water in the tank at the moment it dropped away. As it did, the drop would carry charges away with it. This continues until equilibrium was reached between the tank and the air.

Using this same idea, charging time can also be reduced by

spraying a fine mist of water along a bare copper wire a hundred feet or more in length which is insulated from and suspended above ground. The falling water droplets can help to charge this wire to a measurable level in less than a minute's time.

Another method of speeding up the charging process is to increase the number of ions in the vicinity of the wire itself. A flame applied to the wire will increase the number of ions in the area of the flame and can bring a wire up to the same potential as the air around it in a matter of seconds. To accomplish this easily, wrap the wire with a flammable substance such as string or paper soaked in lead nitrate, and ignite it. It is also possible to get good results by simply waving a torch lightly across the wire.

In Conclusion

I hope that you will enjoy experimenting with electrostatics as much as I have! I find few subjects more fascinating than high voltage and its generation. As a technically minded person, you will undoubtedly see many improvements that can be made in my designs. I know that this is true because at times it seemed I might never complete this text because there was always one more improvement to make and one more experiment to try. No doubt, you will conceive of dozens of new ways to apply the basic principles of electrostatics. Like all experimentation, every change, every test, every improvement will suggest many more questions to be answered and new improvements to be made. You'll probably devise many new inventions!

Electrostatics is also a subject that everyone is absolutely fascinated by – even those who can't change flashlight batteries,. When I was experimenting with different friction generator materials, I purchased quite a number of little swatches of material from a local fabric store. The young ladies working in the store demanded to know what the fabric was for, and, were so fascinated by the idea of generating a spark that I emerged from the store piled high with swatches of material which they insisted be tried on the generator.

My own mother, who despises anything technical, shocked me to no end by demanding that I explain to her the workings of the atom immediately after seeing the classic Van De Graaff in operation. I do not think anyone can watch a powerful Van De Graaff generator at

work and not be curious about the forces at work. (And you and I will always want control of those forces!)

So dig in, get to work! Mysteries await!

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ADDENDUM

Electroplating High Potential Terminals

As you have certainly realized by now, a tremendous amount of your generator's efficiency rests in the quality of your high potential terminal and in your ability to effectively store the charges produced. I think you will be very happy with the performance of any of the classic generators and storage devices described earlier. However, for those of you seeking to go beyond these boundaries of performance, I'd like to let you in on new area of experimentation: electroplating.

Electroplating is simply a process wherein metal salts such as copper sulfate or nickel ammonium sulfate dissolved in an acidic aqueous solution can be deposited as elemental metal on conductor by applying an electrical current. This means simply that any conductive object can be covered through the process of electrodeposition with a layer of metal!

Since electrostatic charges can be distributed quite nicely on even very thin conductive surfaces, this is a perfect system for making a flawless Leyden jar or a huge high potential terminal. I am currently working on creating very large, near-perfect high potential terminals by plating large plastic globes sold in many lighting stores for under $15.00!

Anything can be plated – plastic, glass, pvc, etc. The only trick is in making their surface conductive initially so that a current can be applied.

The basic procedure for producing a perfect Leyden jar is as follows.

Begin by making the glass jar extremely clean. No fingerprints, water, or oil of any kind can remain. Use masking tape to cover the top 20% of the jar to prevent plating in this area and to preserve a well-proportioned jar. Paint the exposed glass with a resin such as white shellac thinned with denatured alcohol, if necessary. I've even used a spray lacquer.

From here there are several routes that you can take. The easiest method is to take a finely powered metal such as iron or aluminum (something around 400 mesh) and sprinkle it on the sticky, wet shellac. Since these finely powdered metals will float in the air much like

talcum powder, I usually put the metal powder and jar in a box and shake the two around around. Remember! These metals SHOULD NOT BE INHALED! Wear a safety mask, and if working with heavy metals, wearing protective clothing is a good idea. The metal powder should create a beautiful, even, light coating over the painted surface of the jar. Allow the paint to fully dry, and repeat the procedure on the inside of the jar. This is a little trickier, but not impossible.

At this point you can actually stop, and use the jar quite successfully. The tiny sandpaper edges of this powder metal coating will bleed off a stored charge when the jar is not in use. This makes a good natural safety feature.

The only drawback to the powdered-metal approach is that if you choose to copper plate it, the copper plating will be just as bumpy as the powdered metal surface itself. As a result, this method will always allow some leakage.

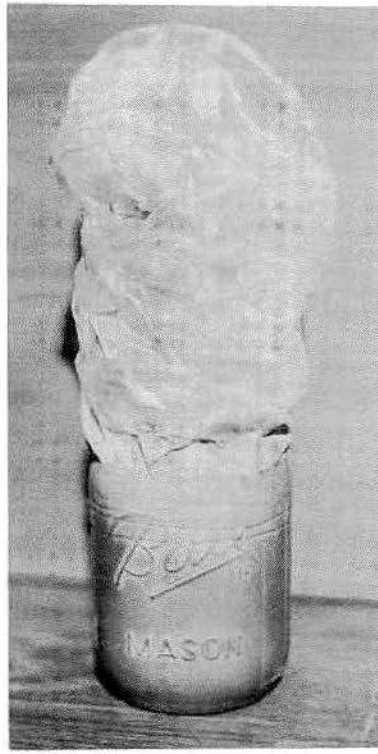
Another simple method of making the jar conductive is to cover the shellac with powdered graphite. This can be rubbed smoothly onto the surface when the shellac is partially dry and will provide a smoother surface which in turn will produce smoother plating. On the other hand, graphite surfaces often require considerably longer plating times and the process is less reliable.

Although both of the above methods work well and have merits, the very best way to make the jar or any non-conductor conductive is to allow the shellac to dry completely, then paint or dip it in a solution of

1/2	ounce	silver nitrate
4	ounces	distilled water
6	ounces	alcohol

While this is still wet, suspend the jar inside a larger jar or other acid-proof non-metallic vessel, and place a few lumps of potassium sulfite or iron pyrite in the bottom of the larger jar. Cover this with a solution made up of one part sulfuric acid and eight parts distilled water, and close the lid. You now have a jar covered with silver nitrate solution hanging above the potassium sulfite-acid solution in a sealed vessel. This will produce hydrogen sulfide fumes that will convert the nitrate to a sulfide which is a conductive coating for you jar. Within a

A glass jar for the Leyden jar capacitor is selected and thoroughly cleaned.



The jar is masked off and coated with conductive graphite.

few minutes the chemical reaction will stop, and your jar will be ready to be plated.

Now that the outside of the jar has been made conductive, it can easily be plated with copper. In an appropriate acid-proof vessel, make a solution of

25	ounces	copper sulfate
6	ounces	sulfuric acid
1	gallon	distilled water

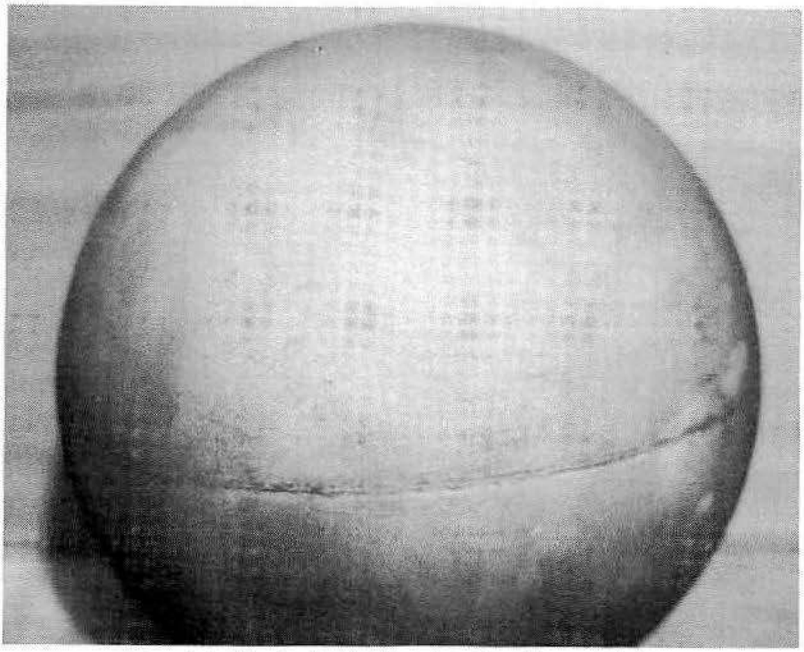
Use warm water when mixing to dissolve the copper sulfate more quickly. Do not allow this solution to touch your skin or clothes.

After a few hours, the deposit of copper is easily seen.

The plated jar is ready to be cleaned up and put into use.

Attach a wire from the negative lead of a 2 to 5 volt battery or transformer to the conductive part of your jar. A rubber band works well for this. Immerse the portion of your jar to be plated in the copper sulfate solution. Finally, attach a wire from the positive lead of your power source to a copper electrode having a large surface area such as a thin copper sheet. Set this electrode in your solution.

All that you have to do now is watch the jar as the plating takes place. Be sure you keep the solution warm, or the plating will proceed very slowly. I like a thick copper coat and usually allow my plating to take place overnight. However in a fairly short period of time you should see a reddish copper coating forming on the outside of your jar! Simply repeat this process for the inside of your jar.



A twelve inch plastic sphere has been coated with graphite and is ready to be plated.

Very large spheres and other shapes can also be plated by scaling up this process. I have seen many inexpensive large glass and plastic globes since I began experimenting with this process that would lend themselves to this technique. For more information, refer to books on electroplating and electroforming that can give you advanced details on plating superior finishes.

As you can see, simple electroplating can make possible a vast number of new shapes and designs for high voltage terminals!